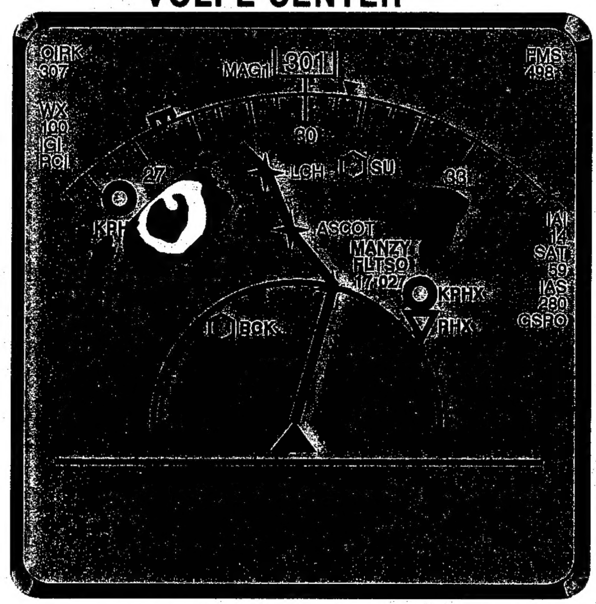
A Human Subject Evaluation of Airport Surface Situational Awareness Using Prototypical Flight Deck Electronic Taxi Chart Displays

DOT/FAA/AR-95/103
DOT-VNTSC-FAA-95-36

Office of Aviation Research
Washington, DC 20591

VOLPE CENTER



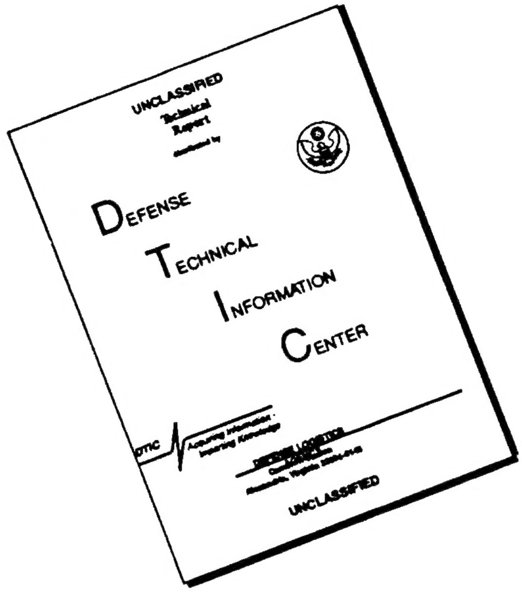
COCKPIT HF PROGRAM

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Final Report
November 1995

U.S. Department of Transportation
Federal Aviation Administration

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
November 1995

3. REPORT TYPE AND DATES COVERED
Final Report
August 1993 - August 1995

4. TITLE AND SUBTITLE
A Human Subject Evaluation of Airport Surface Situational Awareness Using Prototypical Flight Deck Electronic Taxi Chart Displays

5. FUNDING NUMBERS
FA5E2/A5007

6. AUTHOR(S)
Marc J. Amar*, R. John Hansman*, Jr., Daniel J. Hannon, Thomas W. Vaneck*, Atif I. Chaudhry*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FAA-95-36

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Aviation Administration
Chief Scientific and Technical Advisor for Human Factors
Washington, DC 20591

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FAA/AR-95/103

11. SUPPLEMENTARY NOTES
*Aeronautical Systems Laboratory
Department of Aeronautics & Astronautics
Massachusetts Institute of Technology
Cambridge, MA 02142

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
A study was conducted to test the effect on airport surface situational awareness of GPS derived position information depicted on a prototypical electronic taxi chart display. The effect of position error and position uncertainty symbology were also tested. Situational awareness was assessed by asking 12 airline pilots a series of probe questions about their location on the airport surface. The pilots used static "snapshot" images of a north-up electronic taxi chart as well as a supporting out-the-window view and an aircraft heading display to answer the situational awareness probe questions.

Four levels of GPS position error were tested ranging from 4.5 to 90 meters. Two types of position uncertainty symbology were also tested. The variable radius uncertainty circle displayed an estimate of the current GPS position accuracy while the constant radius uncertainty circle displayed a worst-case system accuracy of 100 meters.

Situational awareness, as indicated by probe question response accuracy, increased when aircraft position information was displayed on the electronic taxi chart. In addition, response time was also found to improve with the presence of aircraft position information. Response accuracy improved as position error decreased from 90 to 22.5 meters and stayed relatively constant from the 22.5 to 4.5 meter case. Pilots were faster at responding to the probe questions with the variable radius uncertainty symbology. In addition, pilots subjectively preferred the variable radius uncertainty circle.

14. SUBJECT TERMS
human factors, GPS, electronic taxi chart display, situational awareness, instrument landing systems

15. NUMBER OF PAGES
68

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

PREFACE

Airport surface situational awareness is a flight crew's awareness of their location with respect to airport surface features such as runways and taxiways. In conditions of low visibility, the lack of airport surface situational awareness can lead an aircraft to enter an active runway without proper air traffic control (ATC) clearance. This lack of a means by which pilots can safely navigate on the ground in poor visibility conditions has been the cause of many runway incursions and several fatal aircraft accidents.

This study tested the effect on airport surface situational awareness of GPS-derived position information depicted on a prototypical electronic taxi chart display. The effects of position error and position uncertainty symbology were also tested. Situational awareness was assessed by asking 12 airline pilots a series of questions about their location on the airport surface. The pilots used static "snapshot" images of a north-up electronic taxi chart, a supporting out-the-window view, and an aircraft heading display, to answer the situational awareness questions.

Situational awareness, as indicated by probe question response accuracy, increased when aircraft position information was displayed on the electronic taxi chart. Response time, too, was found to improve with the presence of aircraft position information.

This work was supported by the Department of Transportation/Volpe Transportation Systems Center under grant DTRS-57-92-C-00054.

The authors would like to acknowledge the following persons for their contributions to this study:

- Steve Huntley and Dan Hannon at the Volpe Transportation Systems Center, for their valuable assistance in the design and evaluation of this experiment.

- Tom Vaneck and Atif Chaudhry at MIT, for their help with the design and running of the experiment.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (k)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	=	1.1 short tons

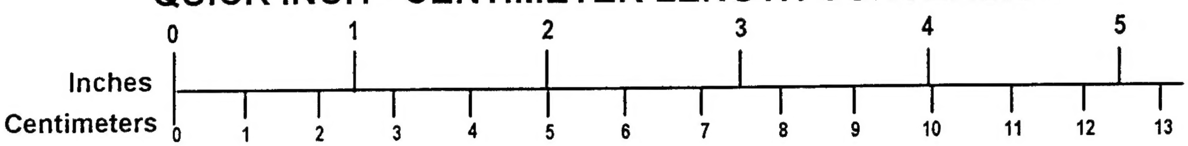
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

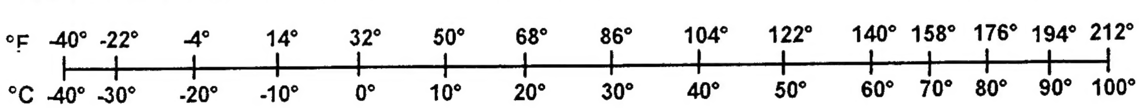
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 1/23/95

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The advent of Instrument Landing Systems has allowed aircraft to safely takeoff and land in low-visibility conditions. However, the lack of a means by which pilots can safely navigate on the ground in poor visibility conditions has been the cause of many runway incursions and several fatal aircraft accidents.

Currently, flight crews use paper chart depictions of the airport surface and out-the-window visual cues to navigate on the surface. In addition, they can be provided with some feedback about their position on the surface from Air Traffic Control (ATC). In clear, daylight environmental conditions flight crews can correlate airport features and navigation signs from the out-the-window view with the chart features to maintain airport surface situational awareness. In conditions of fog and darkness however, out-the-window cues are less available and it becomes a difficult task for flight crews to maintain situational awareness. Low-visibility conditions also prevent ATC from tracking aircraft position on the airport surface from the tower.

Airport surface situational awareness is a flight crew's awareness of their location with respect to airport surface features such as runways and taxiways. In conditions of low visibility, the lack of airport surface situational awareness may lead an aircraft to enter an active runway without proper ATC clearance. This was the case in a ground collision incident at Detroit Metro Wayne County Airport in 1990. A DC-9 mistakenly entered and proceeded to back-taxi down the same runway on which a B727 was cleared for takeoff. The 727 proceeded with the takeoff roll and a head-on collision resulted. Due to fog, tower controllers were not able to see the DC-9 taxi onto the active runway and therefore were not able to warn either of the flight crews. This incident resulted in 8 fatalities and 21 injuries [Harrison, 1991].

To provide some background on the difficulty in maintaining situational awareness during low-visibility taxi tasks as compared to other phases of flight, an informal survey of 19 airline pilots was conducted. The pilots had an average flight experience of 10,250 flight hours. Pilots were asked to rate the difficulty of six phases of a typical commercial flight in terms of maintaining situational awareness on a scale from 1 to 5. The results shown in Figure 1.1 indicate that ground taxi was the most difficult phase of flight to conduct in low-visibility conditions, followed by landing and takeoff. The ground taxi difficulty rating was greater than the difficulty ratings of the other phases of flight, at a 5% significance level (t test).

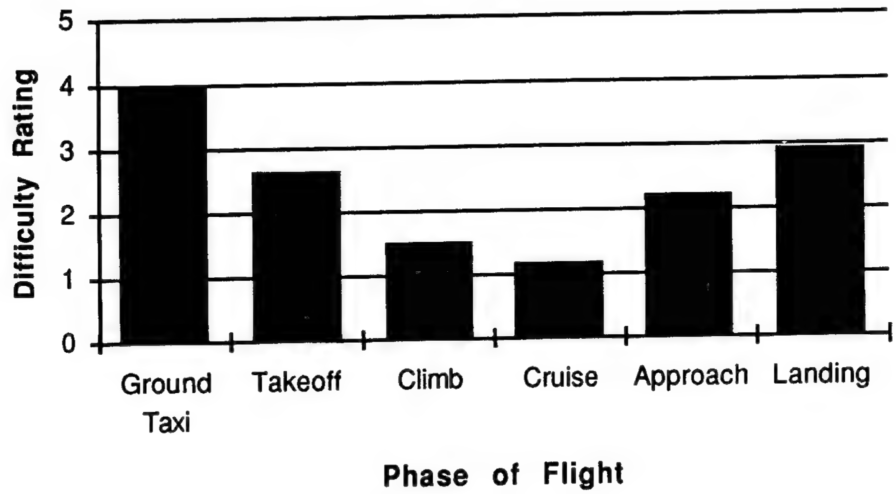


Figure 1.1 Plot of Difficulty of Maintaining Situational Awareness in Low-Visibility Conditions vs. Phase of Flight. 1=Not Difficult 3=Moderately Difficult 5=Very Difficult.

Currently, there are no displays in commercial airline cockpits which show the aircraft location with respect to local airport features to help crews determine their location on the airport surface in low-visibility conditions. However, the advent of high-precision global positioning system (GPS) navigation and display technology has enabled flight deck electronic displays of the airport surface with aircraft position information. Aircraft position can be determined using GPS to better than 100 meters or to even higher accuracy using differential GPS (DGPS). Also, a study on airport surface operations requirements performed by the Boeing Commercial Airplane Group for NASA Langley, recommended the use of flight deck taxi displays with ownship position as a component of a global solution to low-visibility surface operation difficulties [Groce et al., 1993].

The objectives of this study were as follows:

- Determine the benefit of displaying aircraft position on a north-up electronic taxi chart in terms of airport surface situational awareness.

- Determine what effect position accuracy degradation has on pilot situational awareness using a north-up electronic taxi chart. This data can be used to determine position accuracy requirements. Four levels of position error were tested ranging from 4.5 to 90 meters.

- Determine the benefit of graphically displaying real-time knowledge of position accuracy as opposed to the knowledge of worst case position accuracy of the position sensing system.

In order to measure the impact of an electronic taxi chart on airport surface situational awareness, prototypical electronic taxi charts were developed and a test method was developed which involved asking airline pilots a series of situational awareness probe questions. The charts were designed from a Jeppesen Sanderson airport surface chart, Federal Aviation Administration (FAA) standards for airport markings, and feedback from airline pilots. The effect of the electronic taxi charts on situational awareness was tested by asking 12 airline pilots a series of situational awareness probe questions in static "snapshot" scenarios with restricted out-the-window visibility. Independent variables were aircraft position error and position uncertainty symbology. Dependent variables were situational awareness probe question response accuracy which was a measure of situational awareness and response time, as well as pilot subjective measures.

Chapter 2 of this report provides background information on runway incursions, GPS, electronic taxi chart presentation issues, paper airport surface charts, and low-visibility taxi procedures. Chapter 3 documents the development of the prototypical electronic taxi chart format which was used in this study. Chapters 4 and 5 are devoted to explaining the experimental method and protocol. A brief explanation of the methods of data analyses is offered in Chapter 6. Experimental results are presented in Chapter 7. Finally, conclusions regarding this study are presented in Chapter 8.

2. BACKGROUND

This chapter will provide a section on runway incursions and the global positioning system (GPS). In addition, background will be offered on electronic taxi chart presentation issues, paper airport surface charts, and low-visibility taxi procedures.

2.1 RUNWAY INCURSIONS

Runway incursions occur when an aircraft, vehicle, person, or object gets in the way of an aircraft taking off or landing on an active runway. The official Federal Aviation Administration (FAA) definition is :

> *" Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land." [Harrison, 1991]*

Runway incursions are normally caused by human error, either by the ATC controller or the pilot or controller of the surface vehicle. When a human error is committed by the pilot it is often due to a loss of airport surface situational awareness.

Runway incursions are categorized as operational errors, pilot deviations, and vehicle/pedestrian deviations. Figure 2.1 shows a breakdown of the number of incursions for each category during the 4-year period from 1989 to 1992.

It is not unusual for airline pilots to be involved in a runway or taxiway incursion. In order to provide some background on runway incursions, an informal survey was conducted of 19 active airline pilots with an average flight experience of 10,250 hours. When asked if they had been involved in a runway or taxiway incursion or close call, 13 of the 19 pilots said yes.

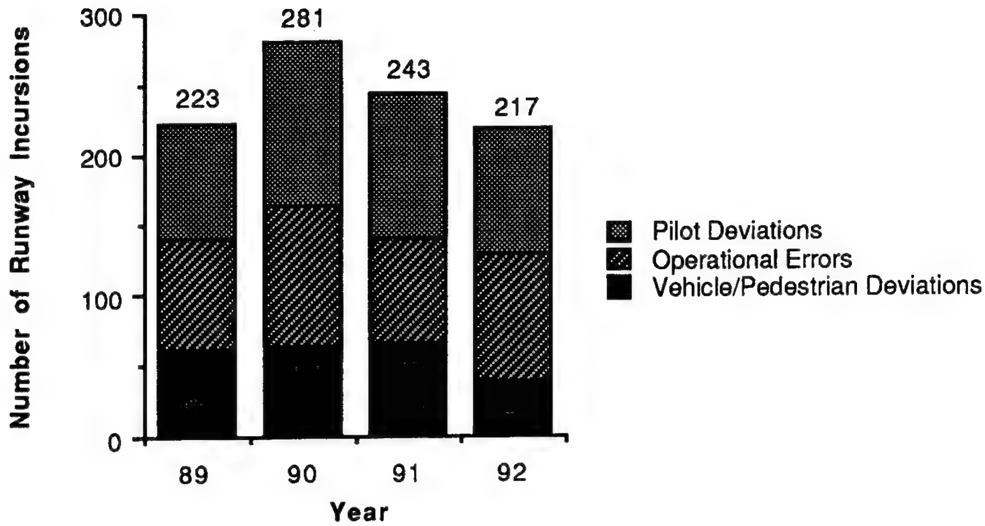


Figure 2.1 Runway Incursions Broken Down By Category for the 4-Year Period Beginning in 1989 [Kasner, 1992].

2.2 THE GLOBAL POSITIONING SYSTEM

One of the key ingredients of the implementation of a flight deck electronic taxi chart with ownship position is an accurate position sensing system. The Global Positioning System (GPS) is a satellite-based navigation system which transmits ranging signals to receivers which then calculate an estimate of position. GPS has currently been certified by the FAA for limited use as a position sensor for approaches [Nordwall, 1994] and is a likely candidate for use in surface operations. Issues that arise in a discussion of GPS are satellite coverage and position error. It is not clear what value of position error will be acceptable for a flight deck electronic taxi chart. It is one of the objectives of this experiment to provide insight into this issue.

GPS position error is defined as the distance from the GPS predicted position to the actual position. For a position sensing system, an estimate of the position error is typically expressed as a level of position accuracy or uncertainty. This position uncertainty is typically expressed as 2σ value which means the position error is within this range 95% of the time. For aircraft in flight a typical error estimate is given in vertical and horizontal components. However, for surface operations only a horizontal estimate of position is required.

GPS position error depends on two primary factors: the geometric configuration of the satellites from which the receiver is accepting ranging signals, and the precision with which the GPS receiver can measure the ranging distance to each satellite. Normally four satellites are needed to obtain a position fix: three to obtain latitude, longitude, and altitude coordinates and one to cancel out clock errors due to the difference in time between the expensive, precise clocks on the satellites and the cheaper, less-precise clocks in the GPS receivers. However, for surface operations, only three satellites are needed because altitude will be known. Position error is lowest when the satellites are widely spread out with large angles between them [Logston, 1992]. The geometrical dilution of precision (GDOP) is a numerical measure of how well the satellites are mutually positioned.

GPS satellites transmit on two L-band carrier frequencies: L1 and L2. The L1 frequency is modulated with the course acquisition (C/A) code and with the precise (P) code. The L2 carrier is modulated only with the P code. The C/A code is available to all users while the P code is restricted to military use. The Department of Defense (DOD) intentionally degrades the C/A code ranging signals for civilian use by method of Selective Availability (S/A). The horizontal 2σ accuracy of GPS for civilian use is considered to be 100 meters. This level of position accuracy was established as a compromise between the FAA (Federal Aviation Administration) and the DOD for civilian use. S/A is not consistently active; it was turned off during the Gulf War to allow coalition forces to obtain the best GPS positioning accuracy [Logston, 1992]. Currently, it is not clear whether it will remain on in the future.

Experimental tests have shown different levels of position accuracies. A study was completed in which a ground vehicle fitted with a GPS receiver was used to determine GPS static position accuracy at Chicago O'Hare International Airport in 1992. The GPS data was shown to have a 2σ accuracy of 41.32 meters for 2,489 trials [Hoffelt et al., 1992]. It is important to state that these are position accuracy values for the time and location stated. Position error will vary with the number of satellites in view which is dependent on time and location, as well as the integrity of the ranging signal.

A method for improving the position accuracy is differential GPS (DGPS) (Figure 2.2). This method provides a stationary receiving station on the ground at a known location. This differential station receives the ranging signals from the satellites and calculates the difference between the position predicted by triangulation and its known position. This correction factor can then be transmitted to local aircraft for improved user position accuracy. DGPS has been shown to provide a 2σ position accuracy of 4 to 5 meters [Hoffelt et al., 1992]. A factor of DGPS is that it is limited to use only at airports or regions which have a differential receiving station.

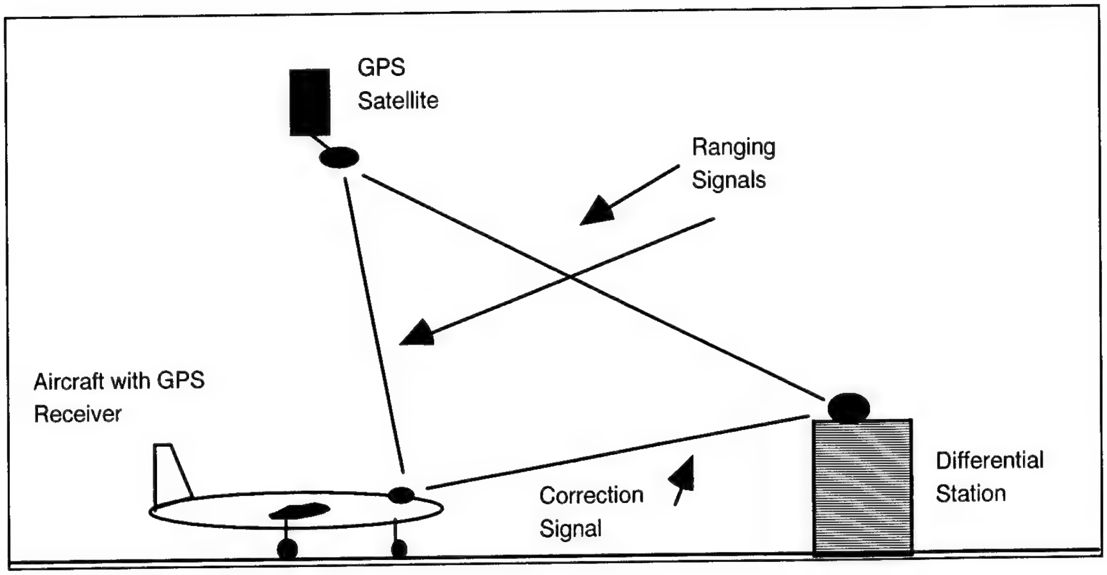


Figure 2.2 Schematic of Differential GPS. For an accurate position fix, three to four satellites are required.

The typical output of GPS receivers is a position fix consisting of latitude, longitude, and altitude. In addition, some receivers will calculate horizontal dilution of precision (HDOP) and vertical dilution of precision (VDOP), and display an estimate of position accuracy.

GPS or DGPS could conceivably be used to provide position information to display aircraft location on an electronic taxi chart. It is also likely that the position accuracy estimate could be displayed as a measure of position confidence.

2.3 ELECTRONIC TAXI CHART PRESENTATION ISSUES

Electronic displays first appeared in aircraft in order to replace conventional electromechanical instruments. The three primary advantages of using an electronic display is the ability to systematically use color coding, the ability to display a mixture of pictorial, text, and numeric formats, and the ability to have the pilots call up a variety of formats on the same piece of display hardware [Wiener and Nagel, 1988]. An example of an electronic display currently used in glass cockpit aircraft is the Electronic Horizontal Situation Indicator (EHSI). The EHSI is a moving map display used to display navigation waypoints en route. An EHSI developed at the MIT Aeronautical Systems Laboratory (ASL) based on a 757/767 display is shown in Figure 2.3. It is likely that an electronic taxi display could be utilized to provide navigation information and enhance pilot airport surface situational awareness using the same display hardware.

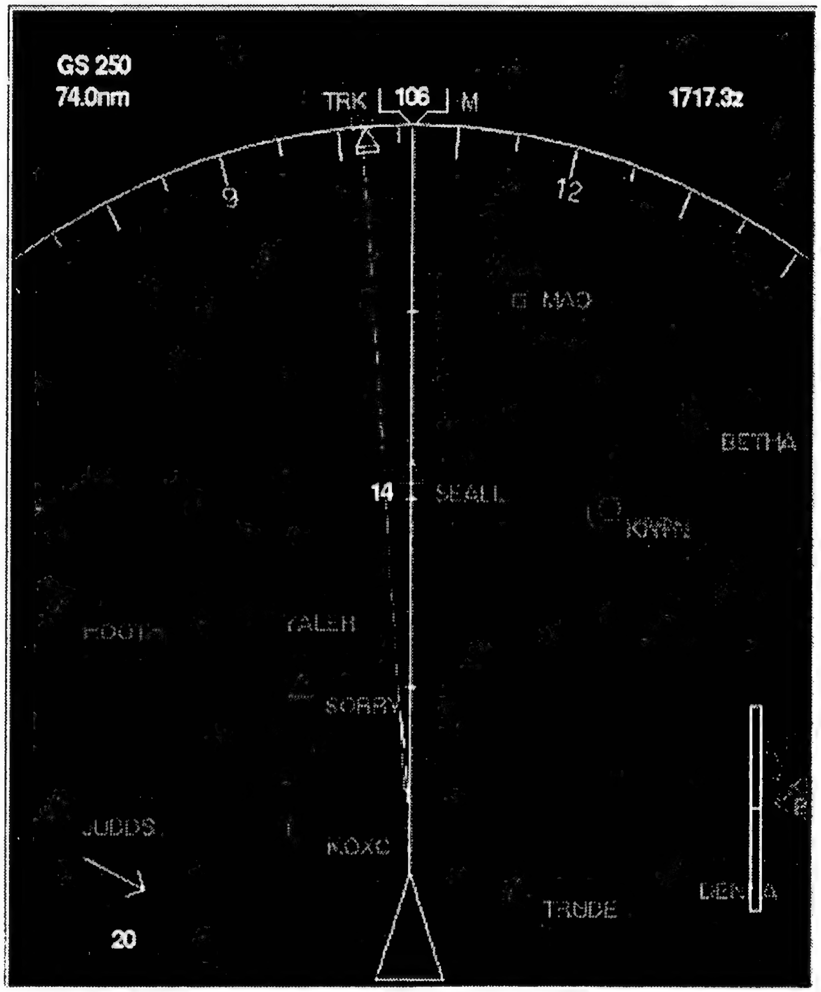


Figure 2.3 Electronic Horizontal Situation Indicator (EHSI), Based On B757/767 Display. Actual Display Is Color.

An issue when discussing electronic maps is whether to display the information in a north-up or track-up (moving map) format. A north-up format would display the airport surface in a north-up orientation. A track-up format would display the airport surface with respect to the ownship aircraft. Typically, the ownship aircraft is placed horizontally at the center and vertically one-third of the way up the chart. Surrounding terrain would then be displayed. The advantages of a track-up chart include the ability to display surrounding terrain always with respect to the aircraft. This is helpful during taxi tasks because the pilot does not have to perform a mental rotation to orient the map to the aircraft heading. An advantage of a north-up format is that there are no text rotation problems because the map orientation does not change. For this study a north-up taxi chart format was developed.

Several organizations have been performing research in the area of electronic taxi charts. NASA Langley has developed electronic displays of airports in Denver and Chicago in effort to investigate situational awareness and the benefit of electronic charts over currently used paper charts [Hunt, 1993]. The Harris Corporation has also developed

some electronic displays of the airport surface in an effort to find a solution to the runway incursion problem [Kulikowsi and Harvey, 1992]. The Harris displays showed all runways and taxiways. In addition, displays of the airport surface are being developed for use in the Airport Surface Traffic Automation Program (ASTA). A simulated surface radar display has been developed and is in use on a demonstration basis at Boston's Logan International Airport [MIT Lincoln Laboratory, 1993]. The display shows runways, taxiways, and ramp areas as well as surface traffic.

An issue that arises in a discussion of displaying aircraft position on an electronic taxi chart is how to display the position accuracy associated with the position sensing system. The worst-case accuracy of the position sensing system can be displayed, or alternatively, the real-time position uncertainty can be displayed. A real-time display of position accuracy would take advantage of increases in position accuracy due to better satellite coverage or other methods of improving accuracy such as DGPS.

2.4 PAPER AIRPORT SURFACE CHARTS

Current charts are plan view depictions of the airport surface and surrounding features. They are used by flight crews to plan and navigate taxi routes at unfamiliar airports. Two organizations produce airport surface charts: the National Oceanic and Atmospheric Administration (NOAA) and Jeppesen Sanderson, Inc. Both organizations distribute the airport surface charts in conjunction with Instrument Approach Plates (IAPs). NOAA charts are contained in bound booklets and redistributed every 58 days [Hansman and Mykityshyn, 1990]. Jeppesen Sanderson charts are contained in a ringed binder and are distributed individually every two weeks.

An example of a Jeppesen Sanderson airport surface chart is shown in Figure 2.4. The main portion of the Jeppesen chart contains a plan view schematic of every runway and taxiway on the airfield, as well as some features of the surrounding terrain such as railroad tracks and objects of altitudes which may be dangerous to local air traffic. Most of the airport surface diagrams are presented in a north-up format. The top portion of the charts contains the name of the airport and the city in which it is located as well as necessary radio frequencies.

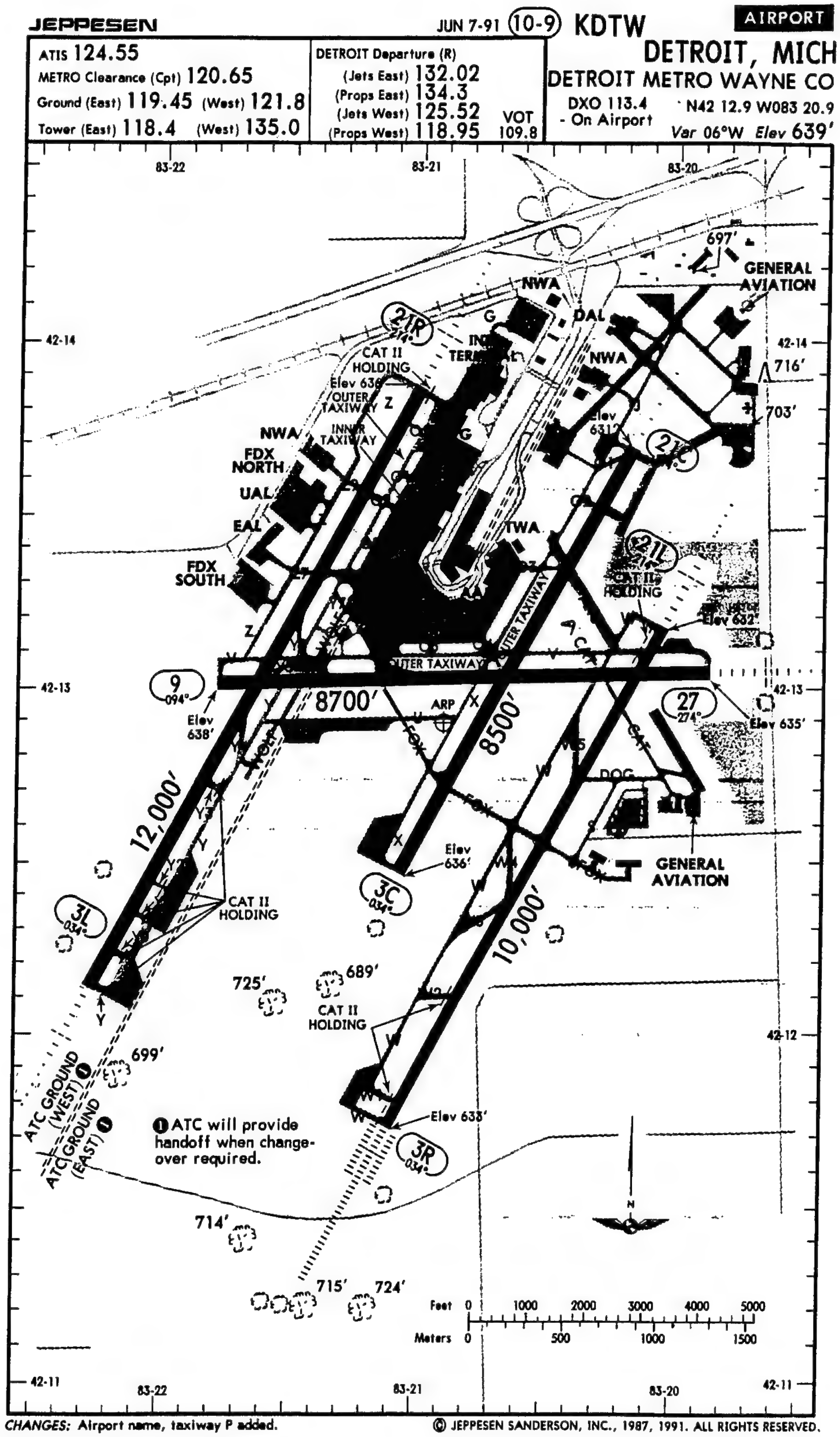


Figure 2.4 Example of Jeppesen Sanderson Airport Surface Chart. Reproduced with permission from Jeppesen Sanderson, Inc.

2.5 LOW-VISIBILITY TAXI PROCEDURES

Currently navigation on the airport surface is accomplished using the cockpit out-the-window view, a paper airport surface chart, and advice from ground and ramp controllers. In low-visibility conditions, follow-me trucks and tugs are sometimes used to guide the aircraft to the gate once it has landed. Flight crews use the paper chart of the airport surface to provide a reference to the flight deck window visual cues. On approach the chart is typically retrieved from its binder within an hour from touchdown at unfamiliar airports. On departure it is typically reviewed at the gate.

Ground taxi operations are broken up into movement and non-movement areas. The movement area covers all taxiways and runways and is governed by ATC ground control. The non-movement area expands the ramp and terminal areas and is governed by local airline ramp controllers at more congested airports.

Low-visibility surface operations for transport category aircraft are normally governed by takeoff and landing restrictions. A decision to takeoff is governed by Runway Visual Range (RVR), which is a measure of the visibility longitudinally along the runway surface in feet. RVR may be measured at the runway touchdown, midpoint, and rollout locations. Landing decisions are based on RVR and a decision height at which the runway must be in sight. Takeoff decisions are based on RVR. Approach and landing RVR minimums depend on guidance equipment at the particular runway and on the particular aircraft. Typically, 600 feet RVR has been the minimum, although some aircraft and runways are certified for 300 feet RVR.

When proper visibility conditions exist to permit takeoffs and landings, ground taxi operations are accomplished with the aid of lighted runway and taxiway identification signs and airport lighting, as well as airport surface charts and communication with ATC ground control. Runways used during very low-visibility operations typically have flush-mounted centerline lights and edge lights, while most taxiways have edge lights. The Surface Movement Guidance and Control system (SMGCS), outlined in an FAA advisory circular, calls for installation of taxiway centerline lights at airports conducting operations below 600 feet RVR [FAA, 1992].

3. DEVELOPMENT OF A PROTOTYPICAL ELECTRONIC TAXI CHART FORMAT

In order to test the effect of an electronic taxi chart on airport surface situational awareness, it was necessary to develop a prototypical electronic taxi chart format. The term electronic taxi chart refers to an electronic display of the airport surface to be used for taxiing purposes.

3.1 ELECTRONIC TAXI CHART

The overall layout of the prototypical electronic taxi chart format resembled that of a Jeppesen Sanderson paper airport surface chart. One of the prototypical electronic taxi charts developed for this study is shown in Figure 3.1. The top portion of the chart contained radio frequencies necessary for approach and departure and the name and location of the airport. The geographical layout of the airport lies in the center and is a scale view. It included a plan view presentation of the runways and taxiways with ID's and airport buildings. In addition, the runway lengths in feet were also displayed.

Although the electronic chart resembles the Jeppesen paper chart, some features not present on paper charts were incorporated. For example, runway centerlines, edgelines, and threshold markers were included on the electronic charts as well as taxiway centerlines. The lengths and widths of the runways and taxiways, as well as the runway and taxiway markings, were depicted to scale.

Color coding of the electronic taxi chart resembled the real world to the extent possible. Runway, taxiway, and ramp areas were dark gray to be consistent with the actual pavement color. Similarly, runway centerlines, edgelines, and threshold markers were white and taxiway centerlines were yellow. The buildings were colored blue. A black background was used to provide contrast.

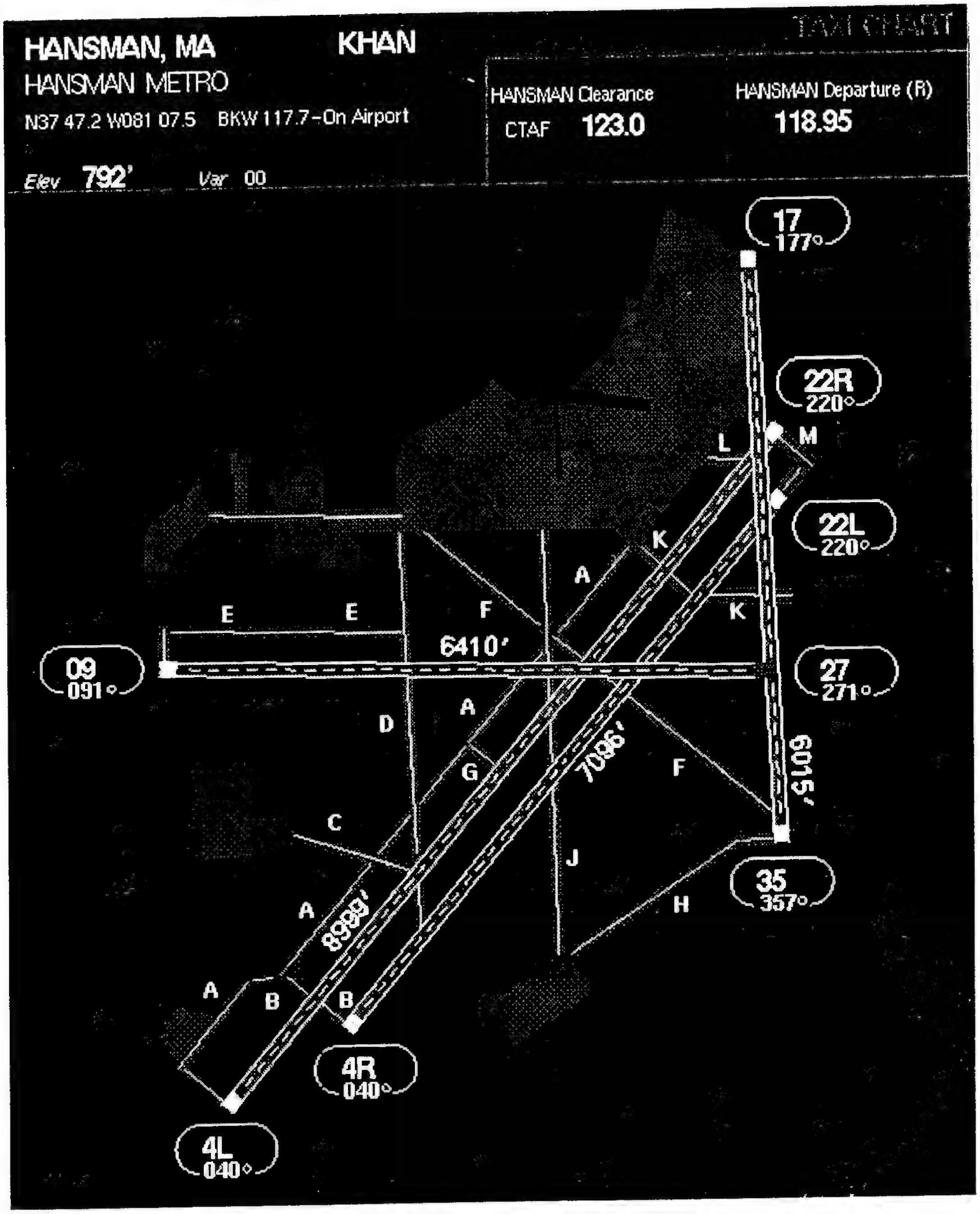


Figure 3.1 Example of Electronic Taxi Chart. Actual size shown.

Although the approach was to have the basic layout resemble a standard paper airport surface diagram, some modifications were made to facilitate using electronic media for presentation. For example, the scale was increased by a factor of 1.13 to allow the airport surface depiction to be as large as possible but still fit the constraints of the standard EFIS display size (5.625" by 6.75"). In addition, the airport runway ID symbology (Figure 3.2) remains horizontal regardless of the orientation of the runway to avoid aliasing effects, where the runway ID symbology on Jeppesen charts is oriented perpendicular to the respective runway centerline.

Figure 3.2 Example of Runway ID Symbology on the Electronic Taxi Charts. The larger font is the actual runway ID while the smaller is the runway heading with respect to North. This symbology was modeled from the runway ID symbology on Jeppesen Sanderson Airport Surface Diagrams. This is the ID for "Runway 18."

Taxiway ID markings were similar to the Jeppesen paper chart's convention. The taxiways were identified by an individual letter from the English alphabet and presented on the electronic chart in capital case. The ID was placed as close to the taxiway as possible without obstructing it.

Text on the electronic taxi chart was sized according to Society of Automotive Engineers (SAE) standards. SAE recommends that electronic display letters and figures subtend not less than a minimum vertical angle at the design eye position of the pilot who normally uses the instruments. SAE recommends a visual angle for three types of data [SAE, 1988]:

Primary data	6 milliradians
Nonessential and secondary data	4 milliradians
Minor descriptive legends	3 milliradians.

The runway ID symbology text as well as the taxiway ID text and runway length text were considered to be primary data for this experiment, and were sized so that they would subtend at an angle not less than 6 radians. A viewing distance of 30 inches was used as a reference value for this experiment (Figure 3.3). The font size used for the aircraft heading in the runway ID symbology was 9 point (this was the smallest of the primary data text). The visual angle for the aircraft heading text was 6.25 milliradians.

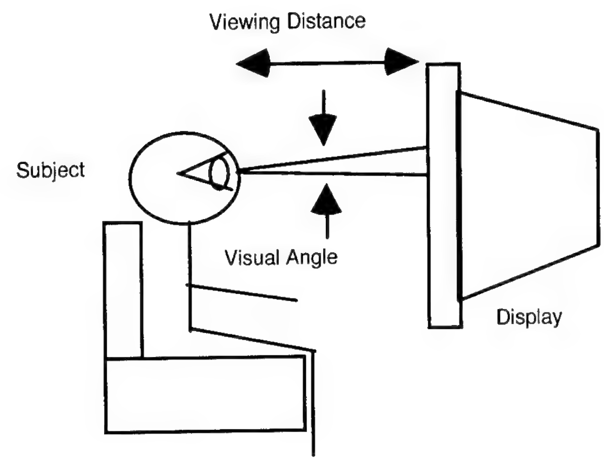


Figure 3.3 Schematic of Subject Viewing Distance and Visual Angle Subtended When Viewing Electronic Taxi Chart Text. Visual angle subtends height of electronic taxi chart text.

3.2 AIRCRAFT POSITION AND HEADING SYMBOLOGY

The position of the aircraft on the airport surface was depicted by overlaying ownship aircraft symbology onto the electronic taxi chart. Three things were displayed with this symbology: the predicted location of the aircraft, the uncertainty of the predicted location, and the aircraft heading. The predicted location was indicated by the apex of a triangular icon. The aircraft cockpit was used as the aircraft reference location. The position uncertainty was indicated by an uncertainty circle centered at the apex of the triangle (Figure 3.4). The uncertainty circle defined the disc within which the cockpit of the aircraft was located. The aircraft heading was indicated by an imaginary bisector of the base of the triangle pointing towards the apex. It should be noted that for this study the heading was assumed to be accurately known.

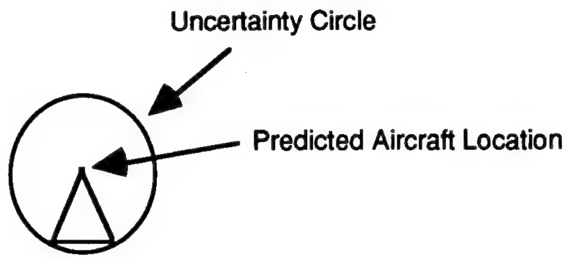


Figure 3.4 Aircraft Triangular Icon and Uncertainty Circle. The uncertainty circle defines the disc within which the cockpit of the aircraft was located.

Two types of uncertainty circles were used, as shown in Figure 3.5. The constant radius uncertainty circle indicated the worst-case system position accuracy, while the variable radius uncertainty circle indicated the actual position uncertainty. The constant radius uncertainty circle was intended to provide the pilot with knowledge of the worst-case system uncertainty, while the variable radius uncertainty circle was intended to provide the pilot with knowledge of the current position uncertainty as a measure of position confidence.

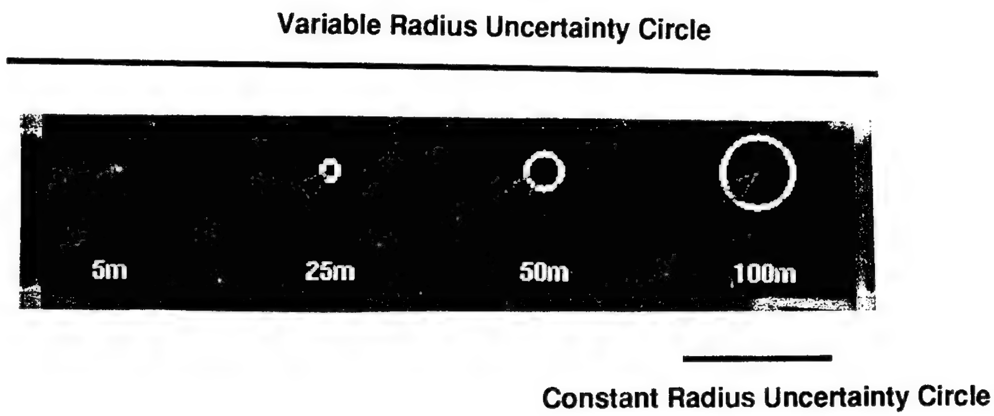


Figure 3.5 Ownship Aircraft Symbology. Values shown are radii of the uncertainty circles in meters. The 5 m uncertainty circle collapses to a point.

The variable radius uncertainty circle had four different radii: 5 meters, 25 meters, 50 meters, and 100 meters. These were chosen to reflect the four different levels of position error used in the study. The constant radius uncertainty circle had only one radius: 100 meters. This value was chosen to emulate the 2σ GPS position accuracy level of 100 meters.

The colors of the aircraft symbology were selected after prototype testing to be clearly visible to the pilot. It was also desired to provide contrast between the uncertainty symbol which represented aircraft location and the triangular icon which represented aircraft heading. Green was selected for the triangular icon and yellow was selected for the uncertainty circle to provide good contrast between each other and the other symbology on the chart.

4. EXPERIMENTAL METHOD

In order to assess the effect of an electronic taxi chart with GPS-derived aircraft position on airport surface situational awareness, an experimental method was developed. The method emulated a worst-case scenario of total disorientation under low-visibility conditions of 600-feet Runway Visual Range (RVR), and tested the ability of the electronic taxi chart to reorient the subject pilot. The method provided the subject pilot with static "snapshot" views of an electronic taxi chart, as well as a supporting out-the-window view and aircraft heading display. The electronic taxi chart depicted the airport surface and sometimes provided aircraft position information, while the supporting out-the-window view and Electronic Horizontal Situation Indicator (EHSI) provided real-world visual cues and numerical heading information, respectively.

The "snapshot" approach was worst case in the sense that the subject pilot did not have the history of taxiing to the point on the airport surface at which he was asked the situational awareness probe question. He was merely presented a "snapshot" of his current situation with the aircraft in a stopped position.

Situational awareness was measured by asking the subject pilots a series of forced-choice probe questions about their location on the airport surface. The subjects were forced to choose one of two answer options. Because of the forced-choice nature of the probe questions, the lowest expected response accuracy would be 50%, which would indicate simple guessing without any situational awareness being provided by the displays. The probe question method for assessing situational awareness was similar to the one discussed in Aretz's *The Design of Electronic Map Displays,* which describes an experiment comparing a track-up, north-up, and a north-up derivative display [Aretz, 1991].

Two quantities were measured: probe question response accuracy and probe question response time. Response accuracy was a measure of situational awareness, while response time was a measure of ease of use of the electronic taxi chart.

Each probe question was asked with a separate "snapshot" scenario. Figure 4.1 is a flow diagram explaining how the "snapshot" scenarios were presented to the pilot. The first situational awareness probe question was brought up on the screen with a keyboard

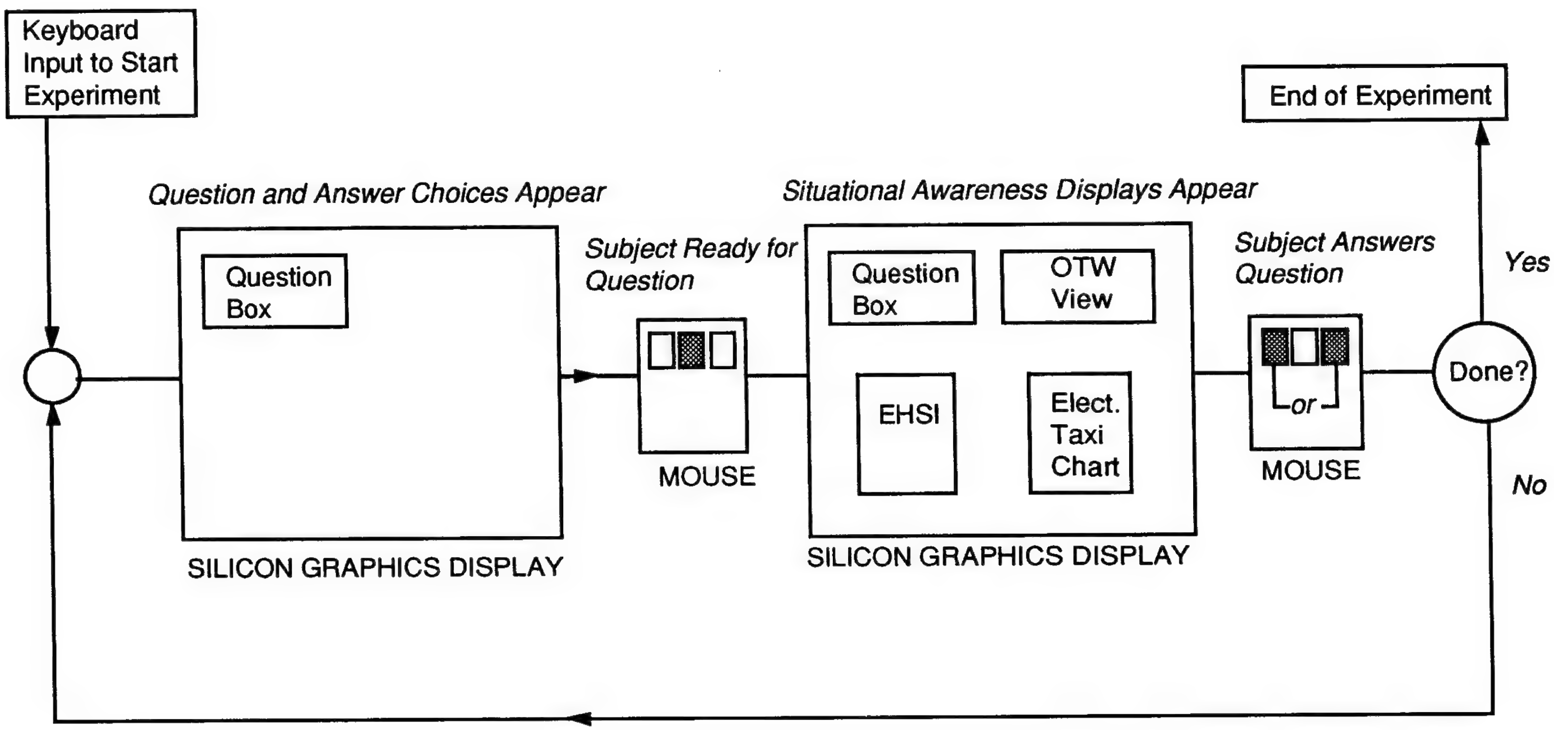


Figure 4.1 Flow Diagram of Presentation of Snapshot Scenarios.

input. It was then intended that the pilot read the question and answer choices prior to viewing the "snapshot" displays in order to avoid measuring the time it took to read and understand the probe question. After reading the questions, the subject then pressed the middle mouse button to bring up the situational awareness displays. The question was then answered with the left or right mouse button. This action brought up a new question. This process was repeated throughout the experiment.

The remainder of this chapter is divided into the Experimental Facilities section and the Experimental Design section. The former will provide information on the electronic taxi chart, supporting simulation, and the automatic data collection system. The latter will provide examples of the situational awareness probe questions and describe the simulation of the GPS position error as well as describe the experimental variables, test matrix, and counterbalancing.

4.1 EXPERIMENTAL FACILITIES

An experimental facility was developed to allow the "snapshot" evaluations of situational awareness with the prototypical electronic taxi chart format discussed in Chapter 3. The facility consisted of the electronic taxi chart, a supporting out-the-window view and the EHSI. The EHSI was used to display aircraft heading. A schematic of the facility is shown in Figure 4.2.

A Silicon Graphics Indigo workstation was used to present the electronic taxi chart and supporting simulation mentioned above. A computer mouse was used by the experimental subject to answer the situational awareness probe questions. The electronic taxi chart presented a plan view of all the runways and taxiways on the airport surface with ID's. The out-the-window view depicted the runways and taxiways from a perspective viewpoint. The EHSI provided the pilot with aircraft heading information.

4.1.1 Electronic Taxi Chart

The format of the electronic taxi charts used in this experiment was described in Chapter 3. Fictitious airports were used in the experiment to avoid prior knowledge effects. Two airports were charted based on the geometries of Cleveland's Hopkins International Airport and the Raleigh County Memorial Airport in Beckley, West Virginia. These two geometries were rotated and flipped to make two additional airports with similar geometry and different orientation. Four airports were used in an attempt to prevent pilots from becoming overly familiar with the airport layouts during the experiment. The airports were selected to have medium complexity. Each airport had a set of parallel runways which were necessary for several of the situational awareness probe questions. The width of all runways was 150 feet and the width of all taxiways was 75 feet. These values were chosen to be consistent with runway and taxiway widths at typical U.S. airports.

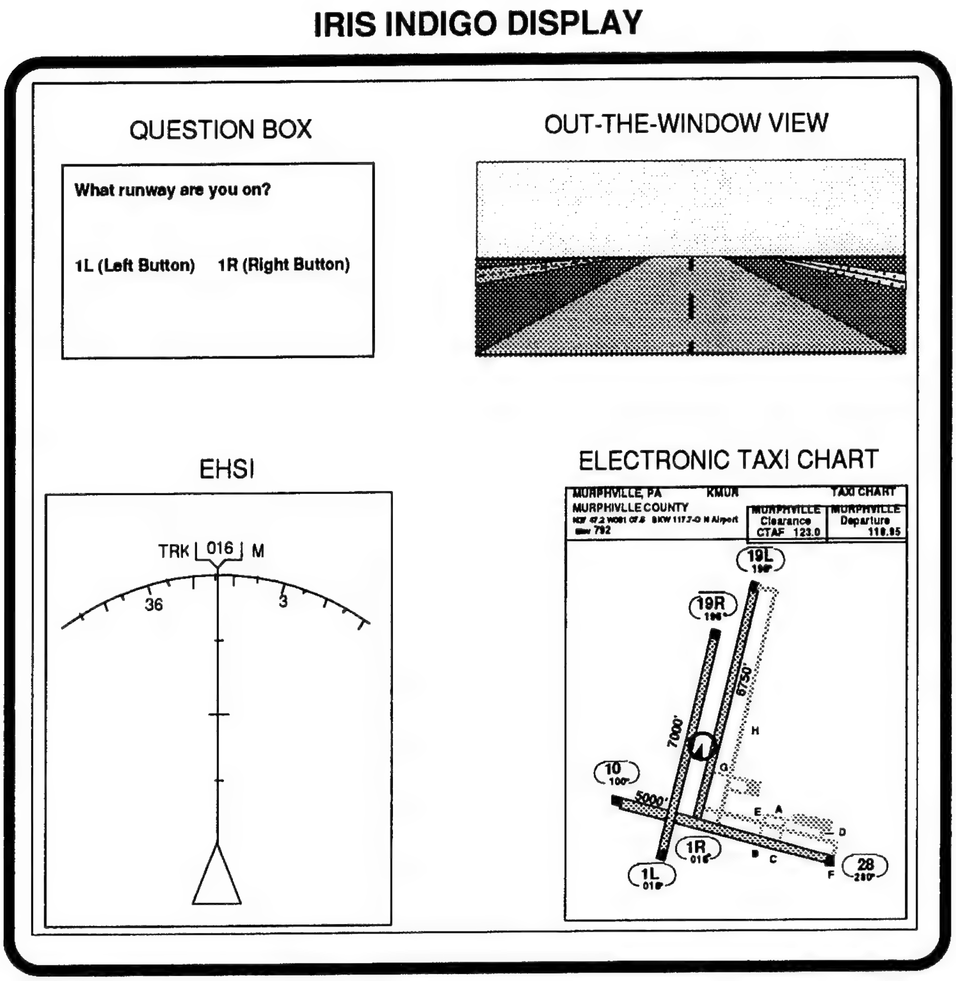


Figure 4.2 View of Experimental Set-up. Shown are the electronic taxi chart, the out-the-window view, the electronic horizontal situation indicator, and a display of the situational awareness probe question.

4.1.2 <u>Supporting Simulation</u>

Supporting simulation was provided to emulate typical situational awareness cues which would be available in low-visibility conditions. Described below are the out-the-window view and the EHSI.

Out-the-Window View

The out-the-window view from a cockpit altitude of 15 feet was used to provide the experimental subjects with real-world visual cues. An example of the out-the-window view is shown in Figure 4.3. During the experiment, a standard fog algorithm was used to reduce the out-the-window visibility. For this experiment the visibility was set to 600 feet Runway Visual Range (RVR). The value of 600 RVR was chosen as a typical value for very low visibility surface operations.

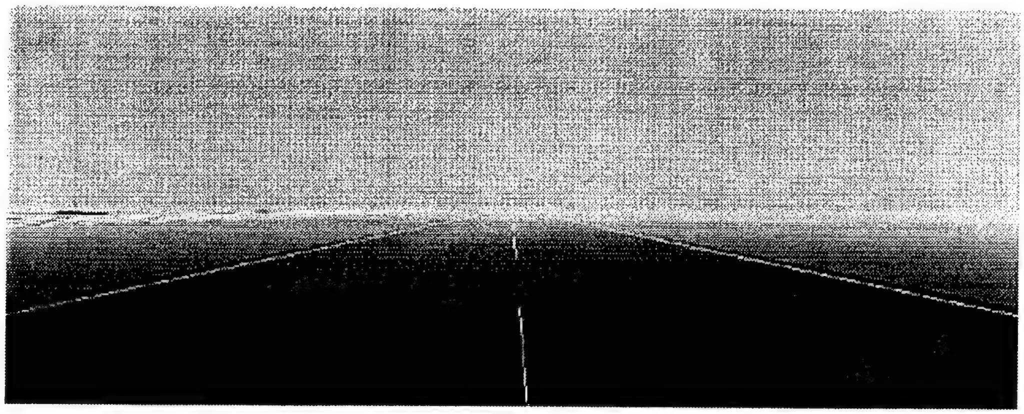
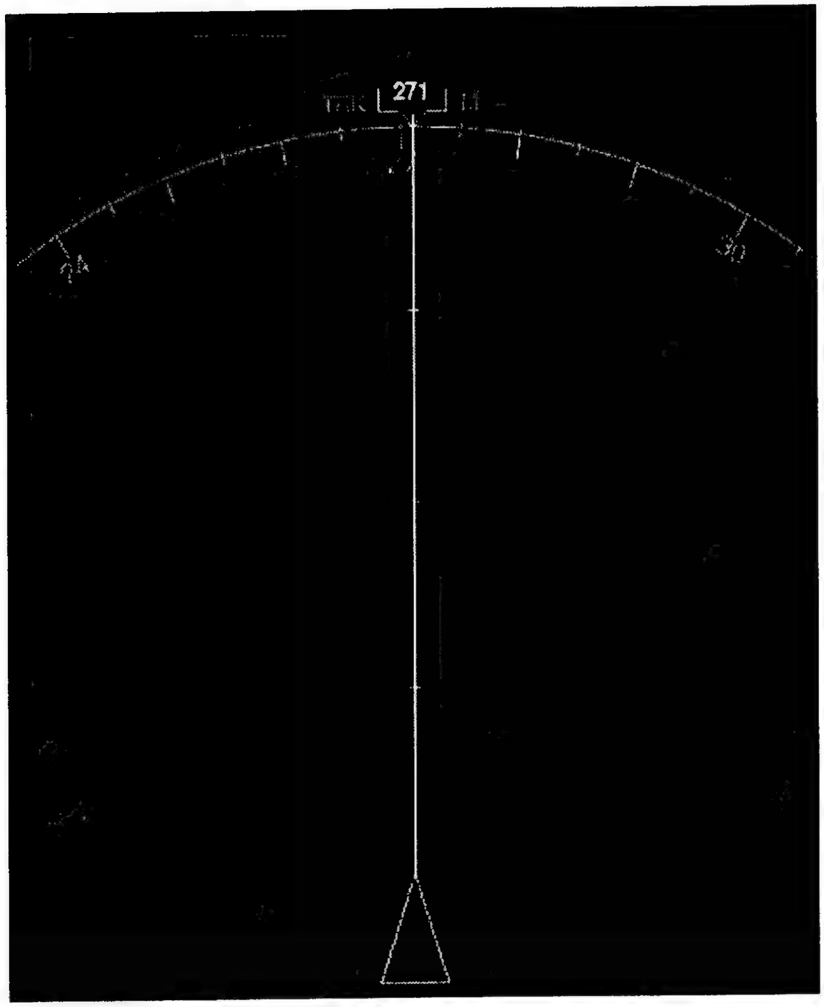


Figure 4.3 Out-the-Window View. Shown with fog algorithm depicting 600 feet RVR. Size reduced by 25%.

The RVR was calibrated by placing a 50-foot-high black square target 600 feet from the runway threshold, placing the aircraft out-the-window view at the runway threshold, and adjusting the fog parameters so that the square was just visible.

Electronic Horizontal Situation Indicator

For this experiment an Electronic Horizontal Situation Indicator (EHSI) was used to display aircraft magnetic heading in a manner consistent with the EHSI in the B767. In actual flight deck use the EHSI can also be used to display navigation waypoints. The EHSI is shown in Figure 4.4.



4.4 Electronic Horizontal Situation Indicator (EHSI) Used in Experiment. Size reduced by 25%.

4.1.3 Automatic Data Collection System

The probe question response data was automatically recorded by the experimental computer facility as shown in Figure 4.5 in order to minimize experimenter bias and to simplify data analysis. The mouse buttons were used to start and stop the timer and record the subject's response to the situational awareness probe question. The subject's response was automatically compared to the correct response in the computer database. The output of the data collection system was probe question response accuracy and response time.

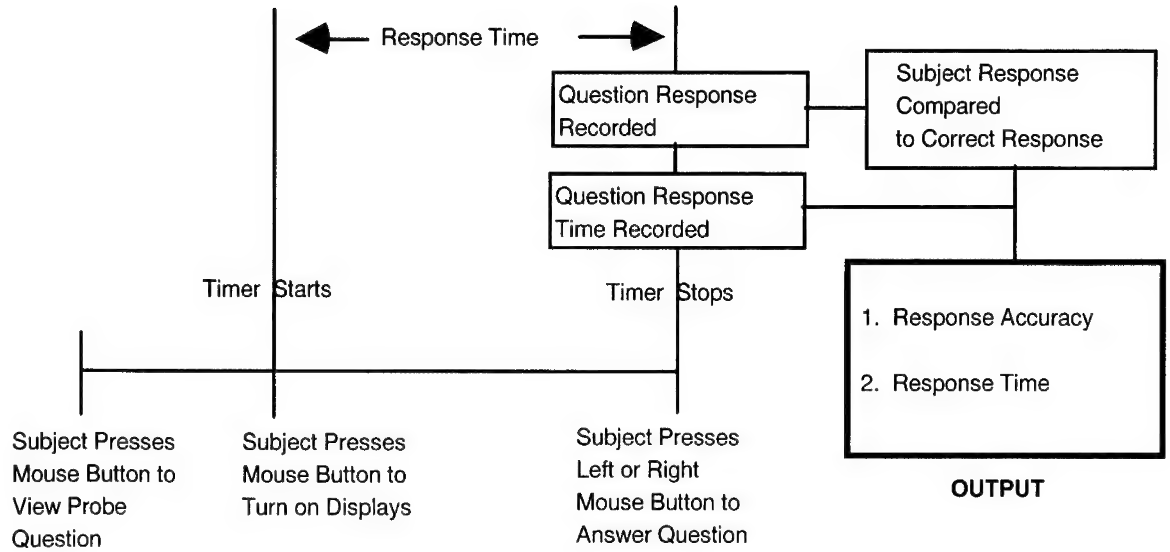


Figure 4.5 Diagram of Automatic Data Collection Process. This process was repeated for all situational awareness probe questions.

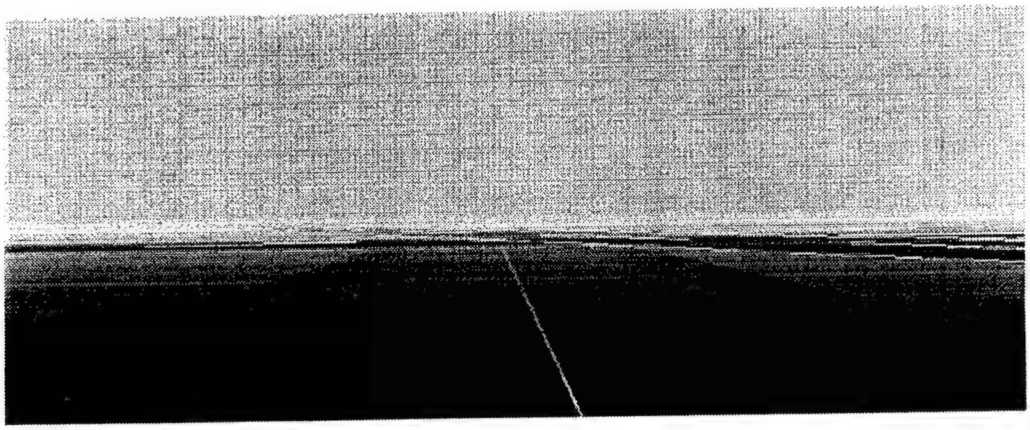
4.2 EXPERIMENTAL DESIGN

The experiment was designed to evaluate the effect of an electronic taxi chart with position information on airport surface situational awareness. Initially, examples of the situational awareness probe questions will be presented. Following will be an explanation of the GPS position error simulation. The experimental variables, test matrix, and counterbalancing will then be presented.

4.2.1 Situational Awareness Probe Questions

The situational awareness probe questions were designed to query the pilot about his or her position on the airport surface. Figures 4.6 and 4.7 are two examples of the situational awareness probe questions with the corresponding electronic taxi chart, supporting out-the-window view and EHSI. Table 4.1 shows the 15 situational awareness probe questions used in the experiment. Each of the 15 probe questions was asked at four separate locations on the airport surface to allow the use of each question for the four position error levels tested. The question asked at these four locations will be considered the four versions of that particular situational awareness probe question.

" *You are cleared to taxi to Runway 4R via Taxiways F, A, and B. Are you following the correct route?* *Yes or No*



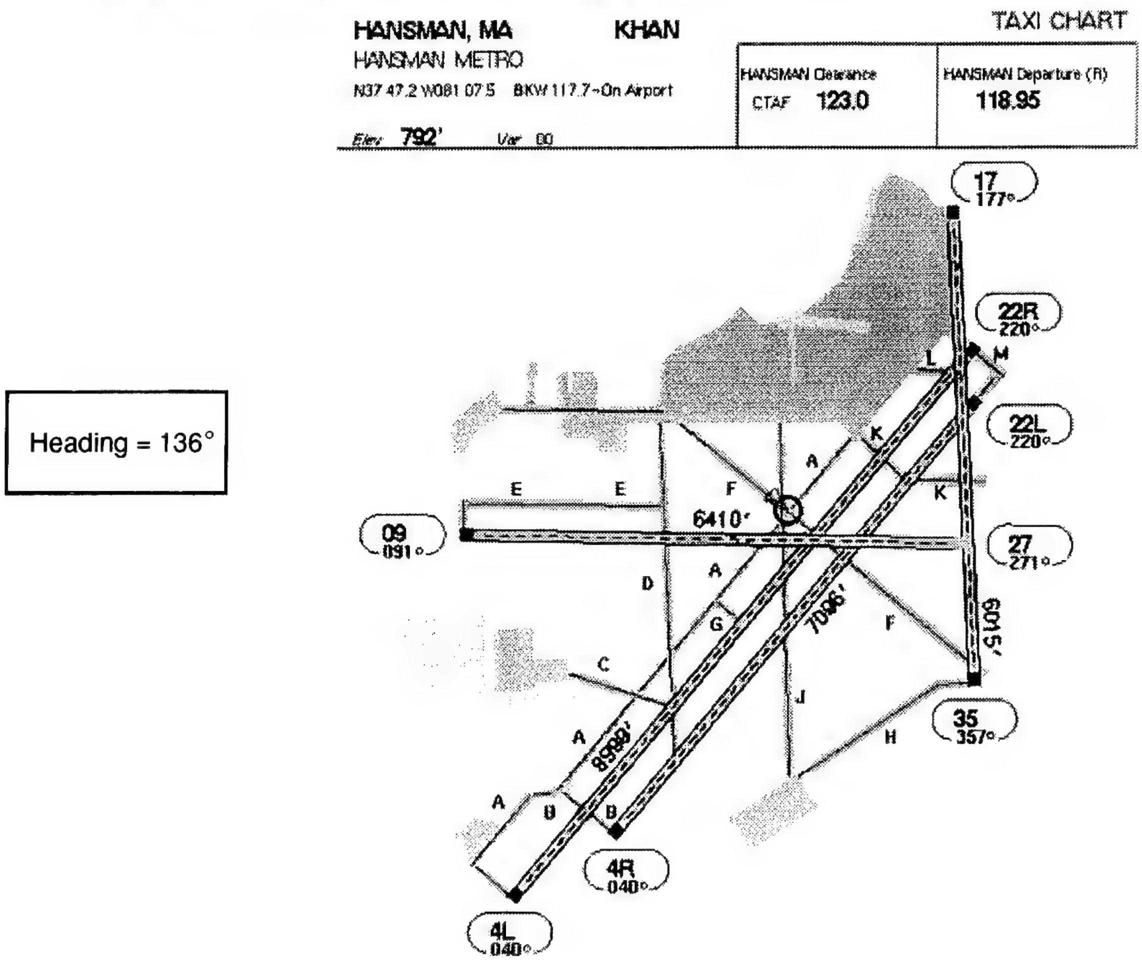
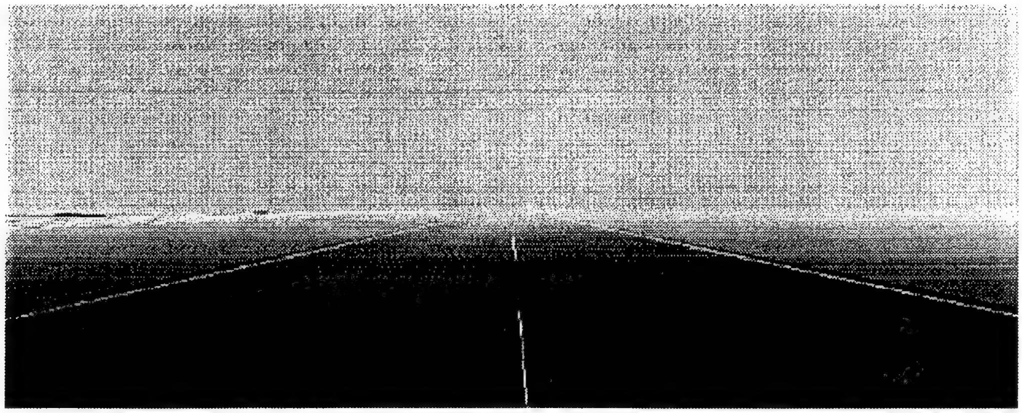


Figure 4.6 First Example of Situational Awareness Probe Question Snapshot Scenario. Shown with 50 m uncertainty circle. Colors of electronic taxi chart inverted for printing purposes.

What runway are you on?" *4L or 4R*



Heading = 40°

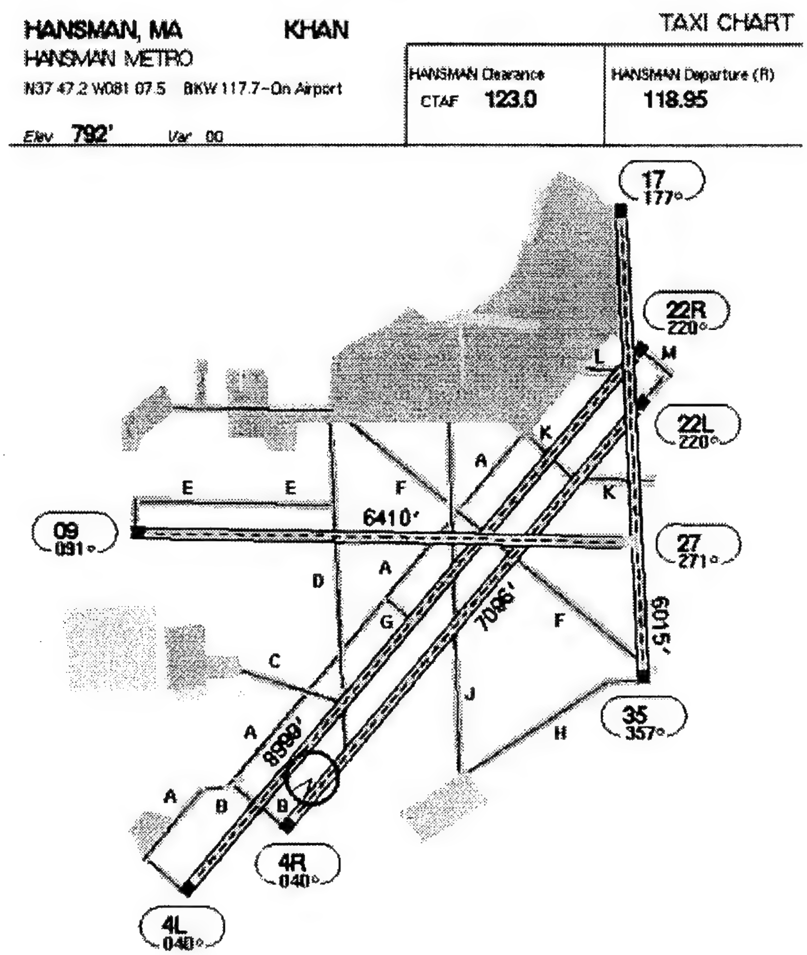


Figure 4.7 Second Example of Situational Awareness Probe Question Snapshot Scenario. Shown with 100 m uncertainty circle. Colors of electronic taxi chart inverted for printing purposes.

Situational Awareness Probe Question	Answer Options
1. What runway are you on?	4L or 4R
2. What taxiway are on?	A or E
3. What runway are you approaching?	23L or 23R
4. What taxiway are you approaching?	E or G
5. Are you on a runway or a taxiway?	Runway or Taxiway
6. What taxiway did you just pass?	X or Y
7. What runway did you just cross?	22L or 22R
8. You are cleared to taxi to Runway 9 via taxiways C, A, D, and E. Are you following the correct route?	Yes or No
9. Runways 9 and 4L are active. Are you on an active runway?	Yes or No
10. You are cleared for takeoff on Runway 1R. An aircraft is backtaxiing on Runway 1L. Are you on the correct runway?	Yes or No
11. An aircraft is approaching and will hold short of Runway 5R-23L on Taxiway V. Can you exit at the next intersection?	Yes or No
12. You have been instructed to hold short of runway 5L due to landing traffic. Should you take immediate action?	Yes or No
13. You are cleared for takeoff on runway 4L. An aircraft is taxiing on Runway 22L. Are you on the correct runway?	Yes or No
14. You are cleared into position and hold Runway 23R. Are you on the correct runway?	Yes or No
15. Taxiways A and C are closed for maintenance. Are you on a closed taxiway?	Yes or No

Table 4.1 The 15 Situational Awareness Probe Questions Used in the Experiment.

The situational awareness probe questions were designed as forced response questions. The subjects were given two answer choices and forced to choose one of them. A "pass" option was not provided. Therefore a response accuracy score of 50% correct would indicate the subject did not perform any better then if he or she had been guessing. Scores higher than 50% indicate the experimental facility provided some increase in situational awareness

4.2.2 GPS Position Error Simulation

The aircraft position and heading symbology overlaid on the electronic taxi chart was displaced a distance from the actual location specified by the position error independent variable. The error was simulated in a worst-case direction which was subjectively assessed by the investigator to be the most ambiguous. For example, for the question, *What taxiway are you on?*, the predicted location of the aircraft was placed in a direction towards another taxiway so it might appear that the aircraft was actually on the wrong taxiway (Figure 4.8).

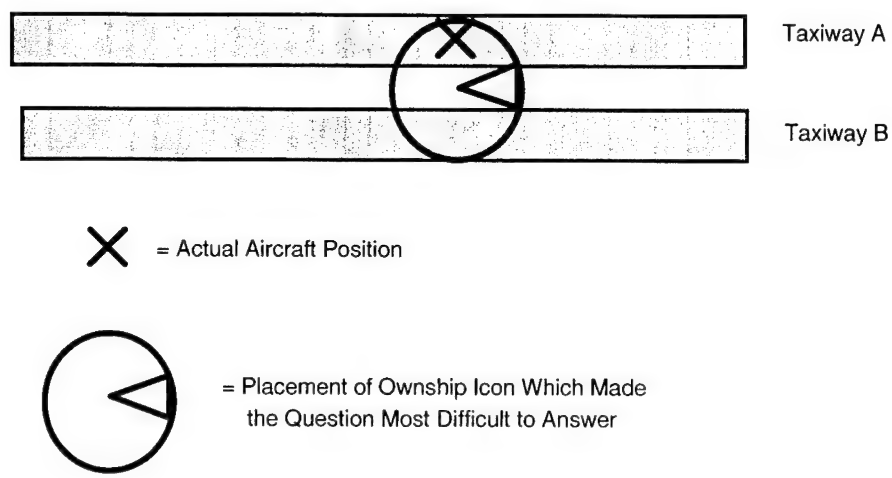


Figure 4.8 Example of Simulation of Position Error on Electronic Taxi Chart.

4.2.3 Experimental Variables, Test Matrix, and Counterbalancing

Initially, the independent and dependent variables will be described. The test matrix and counterbalancing follow.

Independent Variables

Aircraft Position Error - There were four levels of aircraft position error which were defined as the radial distance from actual aircraft location to the predicted aircraft location on the electronic taxi chart. The four levels of position error were 4.5 meters, 22.5 meters, 45 meters, and 90 meters. These values were chosen to provide a broad range of values representing position errors of differential GPS (DGPS) and GPS. These values were 90% of the system accuracy guaranteed by the variable radius uncertainty circle.

Position Uncertainty Symbology - There were two levels of this independent variable. A constant radius uncertainty circle and a variable radius uncertainty circle (please refer to Figure 3.5). The uncertainty circle defines the disc in which the cockpit of the simulated aircraft lies. The constant radius uncertainty circle provided radius of 100 meters for all actual position error values. This worst case value was selected to emulate the GPS 2σ error of 100 meters in the horizontal plane. The variable radius uncertainty circle reflected the current system position accuracy. The four sizes of the variable radius uncertainty circle were 5 meters, 25 meters, 50 meters, and 100 meters. This uncertainty circle provided the pilot knowledge of the actual system position accuracy.

Dependent Variables

Probe Question Response Accuracy - This was the measure of correctness of the response to the situational awareness probe question. Response accuracy was considered to be a measure of situational awareness. The subject was forced to choose one of the two answer choices provided. A "pass" option was not provided.

Probe Question Response Time - This was the time interval from the time the electronic taxi chart appeared until the question response button on the computer mouse was depressed. Response time was considered to be a measure of ease of use of the electronic taxi chart.

Pilot Subjective Opinion - Each pilot's subjective opinion was measured with a written questionnaire. A copy of the questionnaire is available in Appendix. The completed questionnaires provided data on pilot subjective opinions of the electronic taxi chart and the uncertainty circles, as well as data on their flight experience.

Test Matrix

Subject pilots were asked a total of 135 situational awareness probe questions which were distributed about the test matrix shown in Figure 4.9. For each of the nine cells in the test

matrix, a version of each of the 15 situational awareness probe questions was asked. The four versions mentioned in Section 4.2.1 were used for the four position error levels. The same version was used for the constant radius uncertainty circle and the variable radius uncertainty circle at each position error level. The 15 probe questions were also asked for the no aircraft position case which was considered the baseline case. Only one probe question version was used for the "no aircraft position" case since a range of position error levels was not needed.

No Aircraft Position	15 Questions

		Position Uncertainty Symbology	
		Constant Radius Uncertainty Circle	Variable Radius Uncertainty Circle
Position Error Levels	4.5 m	15 Questions	15 Questions
	22.5 m	15 Questions	15 Questions
	45 m	15 Questions	15 Questions
	90 m	15 Questions	15 Questions

Figure 4.9 Experimental Test Matrix. Position Error values given in meters.

Counterbalancing

As shown in the counterbalancing diagram in Figure 4.10, half of the subjects received the "no aircraft position" questions at the beginning of the experiment while the rest received them at the end. Half of the subjects received the variable radius uncertainty circle questions before the constant radius uncertainty circle questions while the rest received them after constant radius uncertainty circle questions. The smaller "no aircraft position" blocks contained 15 probe questions while the larger uncertainty circle blocks contained 60 probe questions spanning the four position error levels. All questions were asked in a random order.

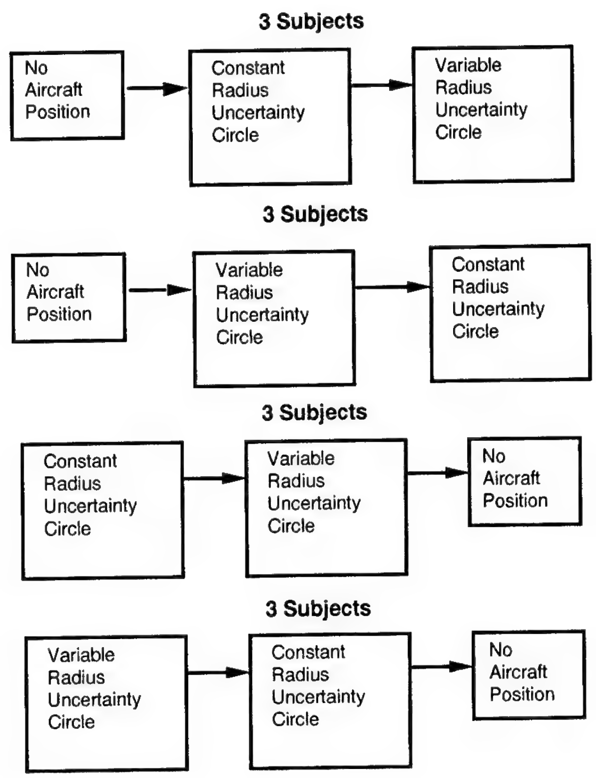


Figure 4.10 Block Diagram of Experimental Test Matrix Counterbalancing.

5. EXPERIMENTAL PROTOCOL

Upon entering the lab, the subjects were asked to complete the first section of the written questionnaire consisting of requests for each subject's flying background and personal information, as well as an informed consent statement. The remainder of the questionnaire was completed after the experiment.

After filling out the first part of the survey, the subjects were instructed to view a display of the aircraft symbology used in the experiment. This was done to familiarize the pilots with the meaning of the symbology. The text identifying the aircraft symbology was also used as a vision test to assure that all pilots could clearly see the necessary information on the electronic displays. To assure the pilot would be able to read all the text on the electronic taxi chart, the text size on the vision test was the same as the smallest text on the electronic taxi chart.

After the pilots felt comfortable with the meaning of the ownship aircraft symbology they were told how the experiment was to be conducted. They were advised there would be four break periods during the experiment. They were also advised that the mouse would be used to answer and select questions throughout the experiment, and that the first priority was to answer the questions correctly and the second priority was to answer the questions as quickly as possible.

When they felt comfortable with the instructions, a demonstration run was conducted. The demonstration run was conducted in order to familiarize the pilots with the experimental setup, consisting of a series of situational awareness probe questions using each level of both independent variables. After the demonstration was completed, the subjects were asked if they had any questions about the experiment. All subjects indicated that they were comfortable with the experimental protocol after the demonstration run was completed.

Once the experiment was started, the subject was the only human input during the experiment and the data was recorded automatically to avoid experimenter bias. The test conductor merely observed the experiment. After the experiment was over the subject pilots were asked to fill out the remaining portion of the pilot questionnaire.

6. DATA ANALYSES

This chapter explains the methods that were used to analyze data collected from the airport surface situational awareness probe question experiment and from the pilot questionnaire collected at the time of the experiment. The method of Analysis of Variance was used to determine the effects of the independent variables on each of the performance measures. In addition, pairwise comparison tests were performed.

6.1 OBJECTIVE DATA

A four-way Analysis of Variance was performed to determine the effects of:

- Position Error (4.5, 22.5, 45, and 90 meters)
- Position Uncertainty Symbol Circle Type (Variable or Constant)
- Presentation Order of Position Icon
  - no position icon question series
  - position icon question series
- Presentation Order of Uncertainty Symbol Circle Type
  - variable radius circle type question series
  - constant radius circle type question series

on each of the performance measures. Table 6.1 shows the counterbalancing. An arcsine transformation of the square root of the response accuracy percentage was used to minimize residual width variations. Statistical data will be presented as both an F-value and a p-value.

Table 6.1 Experimental Counterbalancing.

	Electronic taxi chart with no position icon seen first.	Electronic taxi chart with no position icon seen last
Variable circle type seen before constant circle type	3 subjects	3 subjects
Constant circle type seen before variable circle type	3 subjects	3 subjects

7. RESULTS AND DISCUSSION

Twelve active airline pilots were randomly solicited from a list of airline transport pilots residing in New England. Their average age was 39 with a low of 24 and a high of 50. The average flight experience was 9,058 hours with a low of 2,200 and a high of 20,000. Two of the pilots flew turboprop aircraft with commuter airlines; the rest flew turbofan aircraft for major carriers. Ten of the twelve pilots had experience with EFIS aircraft.* Half of the subjects were captains and the other half were first officers.

7.1 OBJECTIVE RESULTS

Figure 7.1 shows the response accuracy results for all conditions (mean across all subjects). The horizontal dashed line at approximately 78% accuracy is the mean of the results obtained for those question where the pilots were not given a position symbol on

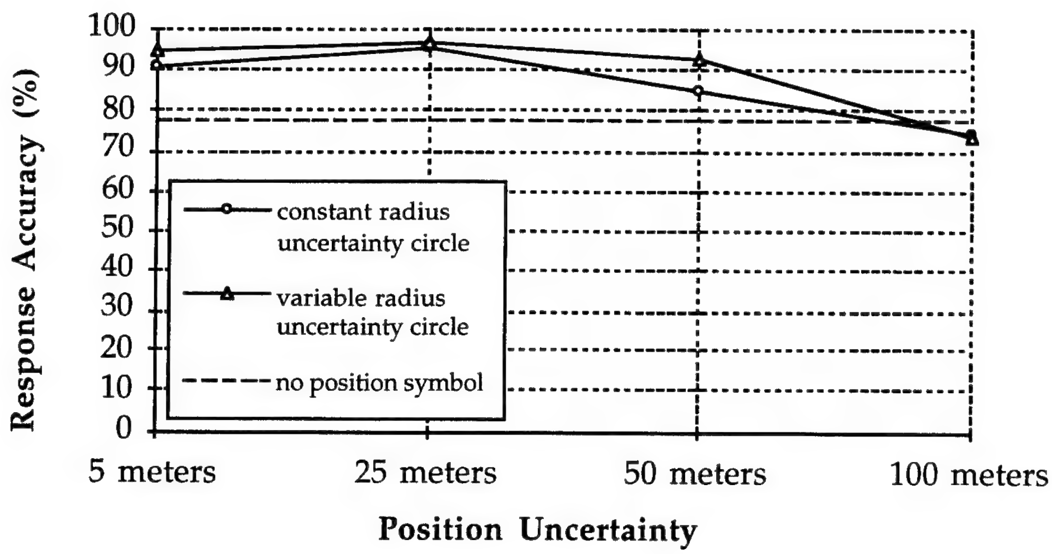


Figure 7.1 Plot of Probe Question Response Accuracy vs. Position Error.

---

* EFIS aircraft include B737-300 and above, B747-400, B757/767, MD-80 and above, amd MD-11.

the electronic taxi chart. The plot shows that there is an improvement in response accuracy as position error decreases, and apparently no advantage of the type of circle. ANOVA results on response accuracy yielded a significant main effect for position error ($F(3,24) = 23.2$, $p < 0.001$). No other statistically significant results were found (i.e. $p < 0.05$). Pairwise comparisons between the means of the different position accuracies yielded no significant differences between the no position circle and the 90 meter position error conditions.

Statistically, significant differences were found between the 90 and 45 meter position error conditions ($F(1,8) = 22.7$, $p < 0.001$), and between the 45 and 22.5 meter position error conditions ($F(1,8) = 24.0$, $p < 0.001$). There was no significant changes in response accuracy to probe questions for position error less than 22.5 meters. These results suggest that up to a point, an improved GPS position solution does enhance situational awareness.

A plot of these data is shown in Figure 7.2. Response latency is plotted as a function of position error with circle type as the parameter. On average, as position error decreases, the response latency also decreases. This effect is greater for the variable circle condition than for the constant circle condition. A four-way ANOVA yielded several significant results. First, there was a significant two-way interaction between circle type and position error ($F(3,22) = 8.18$, $p < 0.001$), and a significant main effect for both circle type ($F(3,22) = 6.52$, $p < 0.05$), and position error ($F(3,22) = 13.93$, $p < 0.001$).

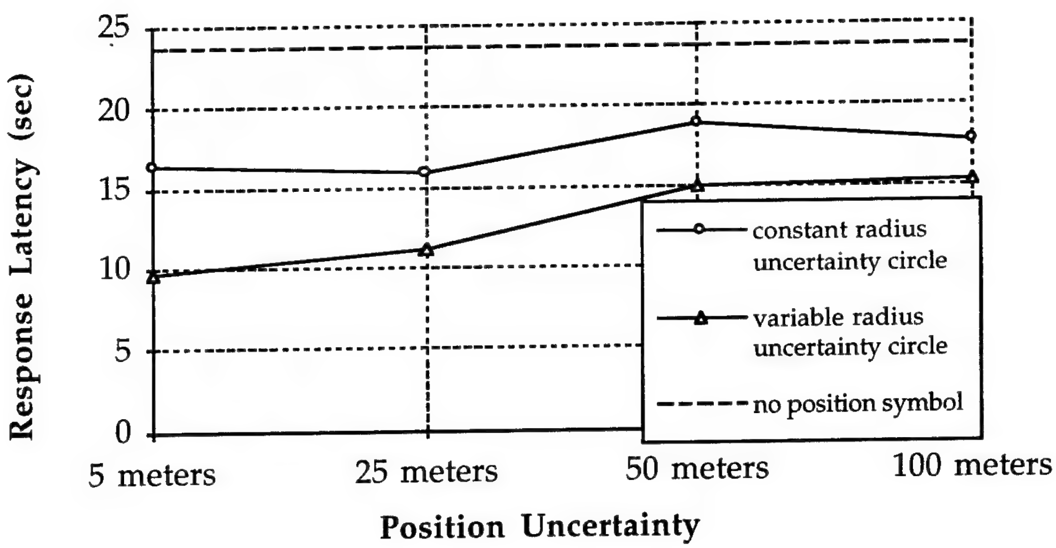


Figure 7.2 Plot of Situational Awareness Probe Question Response Time vs. GPS Position Error.

Pairwise comparisons between means indicated significant differences between constant and variable circle conditions at the 90 meter ($F(1,22) = 15.30$, $p < 0.001$), the 45 meter ($F(1,22) = 43.35$, $p < 0.001$), the 22.5 meter ($F(1,22) = 54.48$, $p < 0.001$), and the 4.5 meter ($F(1,22) = 117.74$, $p < 0.001$) position error levels. Significant differences in pairwise comparisons were also found between: the no position circle and the 90 meter variable uncertainty circle conditions ($F(1,22) = 7.45$, $p < 0.01$), the 45 meter variable circle and the 22.5 meter variable circle conditions ($F(1,22) = 33.28$, $p < 0.001$), the 22.5 meter variable circle and the 4.5 meter variable circle conditions ($F(1,22) = 6.65$, $p < 0.05$), and between the 45 and 22.5 meter constant circle conditions ($F(1,22) = 24.73$, $p < 0.001$). These results indicate that response latency is shorter for all levels of position error for the variable circle condition than for the constant circle condition.

7.2 SUBJECTIVE RESULTS

Each subject completed a written questionnaire depicting their opinions on the electronic taxi chart. The results are presented below.

Usefulness of Flight Deck Electronic Taxi Chart Presentation

Subjects were asked to rate (1 to 5 scale) the usefulness of an electronic taxi chart in terms of their day-to-day flight operations. The twelve pilots gave an average rating of 4 (standard deviation of 1.13), indicating that they felt the electronic taxi chart would be useful in their day-to-day operations.

The Best Features of the Electronic Taxi Chart

In an effort to identify electronic taxi chart feature preferences, pilots were asked to identify the best features of the electronic taxi charts used in the experiment. The subjects' preferences were categorized and the results shown in Table 7.1. In categorizing the results, both aircraft location, and the position uncertainty circles were considered as aircraft position information. As shown in the table, pilots were most enthusiastic about having aircraft position information displayed on the chart.

Table 7.1 Subjective Results Showing Most Liked Features of Electronic Taxi Chart.

Feature	Number of Pilots	Percent of Total
Aircraft Position Information	8	67%
Aircraft Heading Information	5	42%
Airport Surface Features	6	50%

Percentage of Time the Electronic Taxi Chart and Supporting Simulation Were Used During the Experiment

In order to obtain a measure of how frequently the subjects used the electronic taxi chart, the subjects were asked to give the percentage of time they used the electronic taxi chart, and the supporting out-the-window view and EHSI throughout the experiment. The data is shown in a pie chart in Figure 7.3. As expected, the electronic taxi chart was used the most (51% of the time), indicating that pilots considered the electronic taxi chart the primary means for determining situational awareness. The out-the-window view and EHSI may have been used as secondary situational awareness tools.

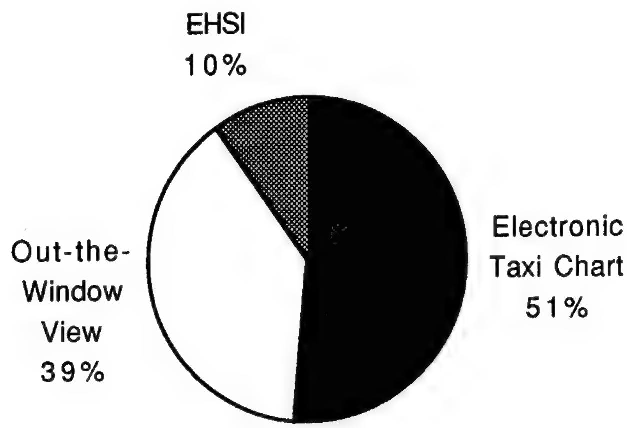


Figure 7.3 Plot of Percent of Time Electronic Taxi Chart and Supporting Simulation Were Used During the Experiment.

Rating of Uncertainty Circle by Size and Position Uncertainty Circle by Type

Seven head-to-head comparisons were made of the different position uncertainty circle conditions. Figure 7.4 graphically presents the results. There was a general preference for higher accuracy depiction.

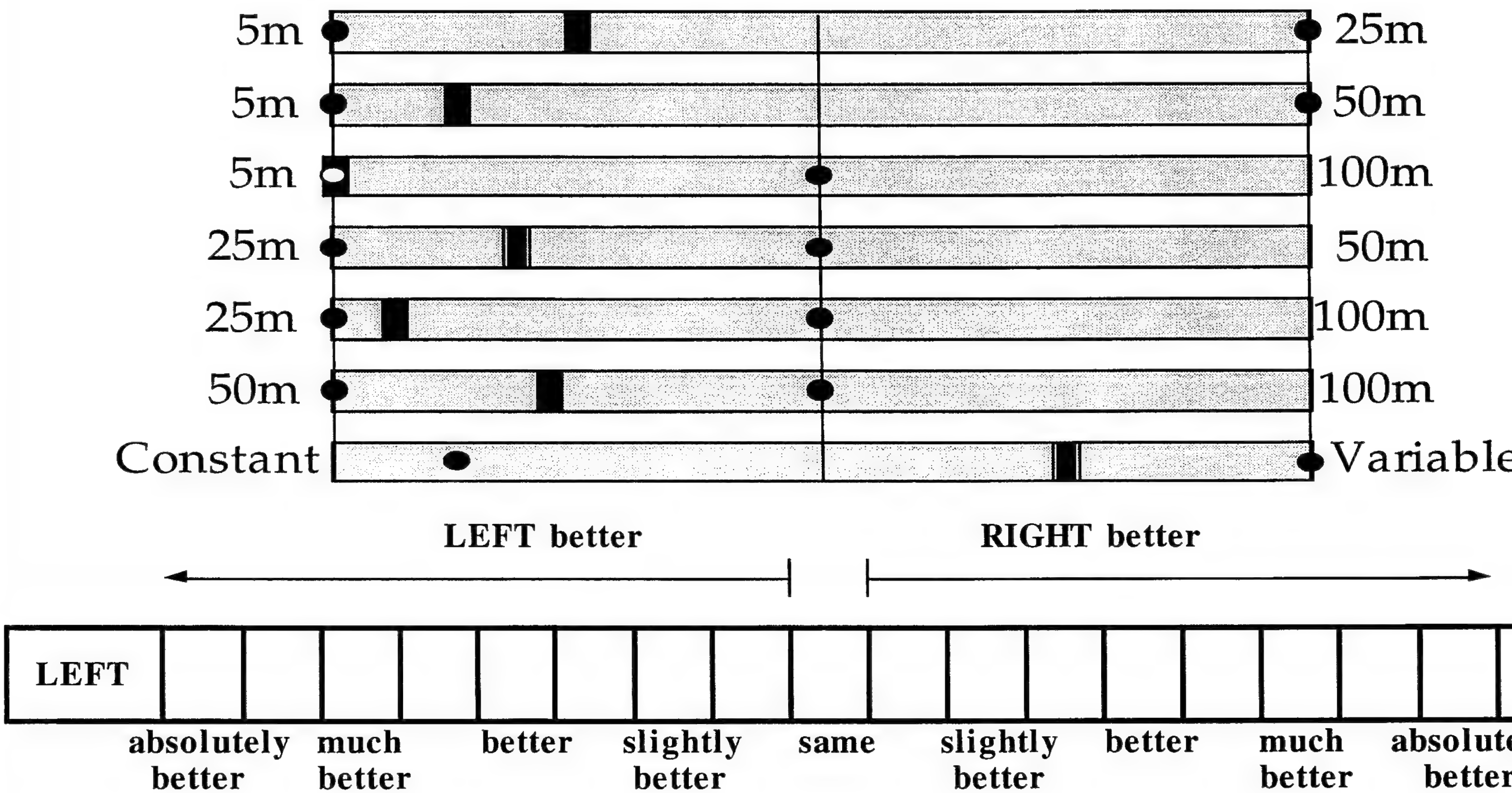


Figure 7.4 Results of Head-to-Head Comparisons. Bar indicates median. Dots indicate extremes.

8. SUMMARY AND CONCLUSIONS

The advent of the Global Positioning System (GPS) has provided a means of providing precise aircraft location information. This position information, coupled with current advanced display capabilities, creates a cockpit-based ground navigation system which may be used by flight crews in low-visibility conditions to maintain airport surface situational awareness, which is a measure of a flight crews' awareness of their location with respect to airport surface features such as runways and taxiways.

This experiment was designed to determine the potential benefit of displaying aircraft position as well as to provide insight on what level of position accuracy may be needed to maintain airport surface situational awareness. In addition, two types of position confidence symbologies were evaluated: the constant radius uncertainty circle and the variable radius uncertainty circle.

Situational awareness was assessed by asking 12 airline pilots a series of probe questions about their location on the airport surface. The pilots used static "snapshot" images of a north-up electronic taxi chart as well as a supporting out-the-window view and aircraft heading display to answer the situational awareness probe questions.

In summary, the major conclusions of this study are the following:

- Results from this study indicate that GPS-derived aircraft position information, when displayed on an electronic taxi chart, appears to enhance situational awareness. The results show that there was a significant improvement for system accuracy better than 50 meters.

- Pilots responded faster to the situational awareness probe questions as the position error level was decreased with the variable radius uncertainty circle. In all cases the subjects responded faster when presented with a variable error uncertainty symbol. This is thought to be due to a perceived increase in system performance, a result that is supported by the response latency results for the 90 meter position error case. Here, both the variable and constant radius uncertainty symbols were identical yet the pilots showed increased performance with the variable radius uncertainty circle symbol.

- Subjective results supported the behavioral data. The pilots showed a stronger preference for the variable radius uncertainty circle symbol with smaller position uncertainty.

- The aircraft position and heading symbology used in this experiment were well received by the subject pilots. When asked to identify the best features of the electronic taxi charts, eight of the pilots mentioned aircraft position information and six mentioned the graphical heading indicator.

REFERENCES

1. Aretz, A.J. 1991. "The Design of Electronic Map Displays." *Human Factors* , 33(1).

2. Curran, Jim. 1992. *Trends in Advanced Avionics.* Ames: Iowa State University Press.

3. Federal Aviation Administration. 1992. *Advisory Circular No. 120-57 - Surface Movement Guidance and Control System* (September).

4. Groce, J. L., Vonbokern, Greg J., and Wray, Rick L. 1993. "Airport Surface Operations Requirements Analysis." *NASA Report CR-191508* (August).

5. Harrison, M. J. 1991. "Runway Incursions and Airport Surface Traffic Automation." *Society of Automotive Engineers Report.* No. 912123.

6. Hoffelt R., Hogg P., Stern R., and Langone, C. 1992. "Initial Operational Results and Revised Objectives of the Chicago GNSS Trials." Aeronautical Radio, Inc. technical report.

7. Horonjeff, R., and McKelvey, F.X. 1983. *Planning and Design of Airports.* New York: McGraw Hill.

8. Hunt, Patricia. 1993. Personal communication. NASA Langley Research Center (July).

9. Kasner, Marsha. 1992. Personal communication. Lincoln Laboratory (December).

10. Kuliwowski, A., and Harvey, M. 1992. "Differential GPS for Control of Surface Operations." *Journal of ATC* (September).

11. Logston, T. 1992. *The Navstar Global Positioning System.* New York: Van Nostrand Reinhold.

12. Lyon, Ervin F. 1991. "Airport Surface Traffic Automation." *Lincoln Laboratory Journal.* Vol. 4, No. 2 (Summer).

13. MIT Lincoln Laboratory. 1993."The Logan Demonstration of ASTA-1." informational brochure (January).

14. Mykityshyn, M.G., and Hansman, R.J. 1990. "Current Issues in the Design and Information Content of Instrument Approach Charts." *MIT Aeronautical Systems Laboratory Report ASL-90-1-1* (November 28).

15. Nordwall, B.D. 1994. "Filter Center." *Aviation Week and Space Technology* (January 10): pg. 67.

16. Society of Automotive Engineers. 1988. *SAE Aerospace Recommended Practice - Electronic Displays Report ARP4102/7* (July).

17. Wiener, E.L., and Nagel, D.C. 1988. *Human Factors in Aviation.* San Diego: Academic Press, Inc.

18. Yang, L.C., and Hansman, R.J. 1994. "A Human Performance Evaluation of Enhanced Vision Systems for Aircraft Approach and Landing Using Computer Simulated Sensor Imagery." *MIT Aeronautical Systems Laboratory Report* ASL-94-3: May 4.

APPENDIX - PILOT SUBJECTIVE QUESTIONNAIRE

Information concerning your aviation background will help us to more accurately assess some of the variables that affect your preferences for airport surface displays. *All information you provide will remain completely anonymous.*

1. Age: __________ Sex: Male ( ) Female ( )

2. How were you *initially* trained to fly? Civil ( ) Military ( )

3. Experience:

   A. Total pilot hours ______________

   B. Pilot ratings held:

   Fixed Wing: ATP ( ) Commercial Pilot ( ) F.E. Written ( )

   Rotary Wing: ATP ( ) Commercial Pilot ( ) Other ____________

   C. Current flight deck position (circle one):

   Captain or First Officer

   D. Current aircraft type _________________

   Number of hours in this type _________________

   E. Please list other aircraft flown for significant periods.

_________________ _________________

_________________ _________________

_________________ _________________

_________________ _________________

4. When conducting flight operations in very low visibility conditions (less than 600' RVR), please rate the difficulty of each phase of flight in terms of maintaining situational awareness.

	Not Difficult		Moderately Difficult		Very Difficult
Ground Taxi	1	2	3	4	5
Takeoff	1	2	3	4	5
Climb	1	2	3	4	5
Cruise	1	2	3	4	5
Approach	1	2	3	4	5
Landing	1	2	3	4	5

5. What percentage of time would you estimate that you have taxied in visibility conditions of:

	0-5%	5-10%	10-20%	>20%
0 - 600 ft. RVR	[ ]	[ ]	[ ]	[ ]
600 - 1200 ft. RVR	[ ]	[ ]	[ ]	[ ]

PLEASE DO NOT PROCEED FURTHER

Post Experiment Questionnaire

1. What are the best features of the electronic taxi charts used in this experiment?

2. What are the worst features of the electronic taxi charts used in this experiment?

3. The definition of a runway incursion is as follows:

   Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land.

   A. Have you ever been involved in a runway or taxiway incursion? Please describe it or the 'closest call'.

B. How could this incident have been prevented?

____

____

____

____

C. Could the airport surface taxi charts with ownship position used in this experiment help to aid in the prevention of this incident?

____

____

____

____

4. In terms of day-to-day operations, how useful would a flight deck electronic taxi chart with ownship position display be?

1	2	3	4	5
Not Useful		Useful		Very Useful

5. Did you feel the size of the error circle had an effect on the time it took you to locate the ownship icon on the taxi display? (Please circle one)

1	2	3	4	5
No effect		Moderate Effect		Large Effect

6. If a variable error circle ownship icon was employed, what is the maximum size error circle you would feel comfortable taxiing with? (please circle one)

5M 25M 50M 100M

7. Please list the percentage of time you used each of the three displays throughout the experiment.

Electronic Taxi Chart ____________

Out-the-Window View ____________

EHSI ____________

CONSTANT SIZE ERROR CIRCLE ICON vs. VARIABLE SIZE ERROR CIRCLE ICON

Which is the "better" ownship icon - CONSTANT SIZE ERROR CIRCLE ICON or VARIABLE SIZE ERROR CIRCLE ICON? Use the scale below to indicate the degree in which one display is better than the other.

CONSTANT SIZE ERROR CIRCLE better | VARIABLE SIZE ERROR CIRCLE better

CONSTANT SIZE																		VARIABLE SIZE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ______________________________

____

____

____

5M RADIUS ERROR CIRCLE ICON vs. 25M RADIUS ERROR CIRCLE ICON

Which is the "better" ownship icon error circle - 5M RADIUS ERROR CIRCLE or 25M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.

5M RADIUS ERROR CIRCLE better ← | → 25M RADIUS ERROR CIRCLE better

5M CIRCLE																		25M CIRCLE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ______________________________

____

____

____

<u>5M RADIUS ERROR CIRCLE ICON vs. 50M RADIUS ERROR CIRCLE ICON</u>

Which is the "better" ownship icon error circle - 5M RADIUS ERROR CIRCLE or 50M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.

← 5M RADIUS ERROR CIRCLE better | 50M RADIUS ERROR CIRCLE better →

5M CIRCLE																		50M CIRCLE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ____

____

____

____

5M RADIUS ERROR CIRCLE ICON vs. 100M RADIUS ERROR CIRCLE ICON

Which is the "better" ownship icon error circle - 5M RADIUS ERROR CIRCLE or 100M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.

5M RADIUS ERROR CIRCLE better ← → 100M RADIUS ERROR CIRCLE better

5M CIRCLE																		100M CIRCLE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ____

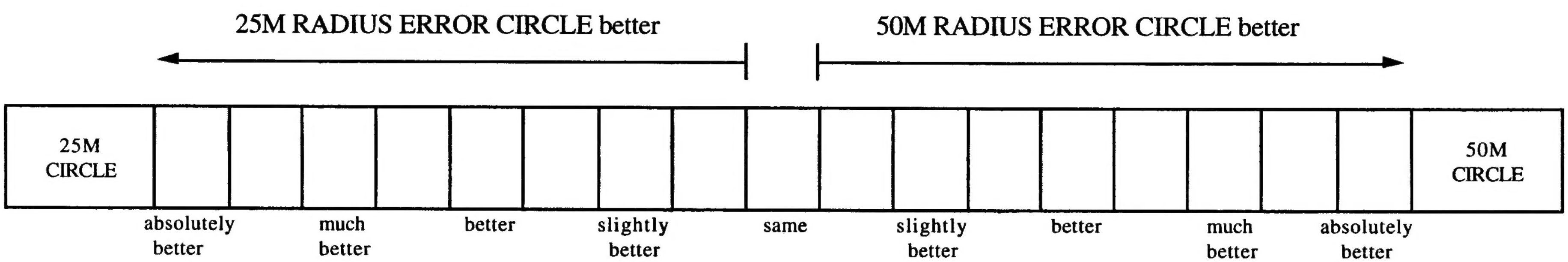
____

____

____

25M RADIUS ERROR CIRCLE ICON vs. 50M RADIUS ERROR CIRCLE ICON

Which is the “better” ownship icon error circle - 25M RADIUS ERROR CIRCLE or 50M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.



Why? ____

____

____

____

25M RADIUS ERROR CIRCLE ICON vs. 100M RADIUS ERROR CIRCLE ICON

Which is the “better” ownship icon error circle - 25M RADIUS ERROR CIRCLE or 100M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.

← 25M RADIUS ERROR CIRCLE better | | 100M RADIUS ERROR CIRCLE better →

25M CIRCLE																		100M CIRCLE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ____

____

____

____

50M RADIUS ERROR CIRCLE ICON vs. 100M RADIUS ERROR CIRCLE ICON

Which is the “better” ownship icon error circle - 50M RADIUS ERROR CIRCLE or 100M RADIUS ERROR CIRCLE?
Use the scale below to indicate the degree in which one error circle is better than the other.

50M RADIUS ERROR CIRCLE better ← | → 100M RADIUS ERROR CIRCLE better

50M CIRCLE																		100M CIRCLE
	absolutely better		much better		better		slightly better		same		slightly better		better		much better		absolutely better	

Why? ____

____

____

____